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Advanced Prototype Direct Reading Instruments for Particular Mass Measurement

Industrial Nucleonics Corp, Columbus, Ohio New Ventures Div

Prepared for

Environmental Sciences Research Lab, Research Triangle Park, N C

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June 1974

Environmental Protection Technology Series

ADVANCED PROTOTYPE DIRECT READING INSTRUMENT FOR PARTICULATE MASS MEASUREMENT

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JUNE 1974

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60-02-0782

Environmental Sciences Research Laboratory
Office of Research and Development
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EPA-ORD

A prototype [illegible] instrument was designed and built to measure the mass of particles in [illegible] emissions from mobile sources. The sensitivity of the instrument is improved over those that were commercially available. The instrument automatically samples exhaust emissions and computes results in [illegible] per mile or meter. All types of mobile sources including catalyst-equipped vehicles and diesel powered vehicles can be sampled by this instrument. The instrument meets the requirements specified in the federal test procedure published in the Federal Register, Part II, Volume 37, Number 221, November 15, 1972.

*Air Pollution
*Instruments
*Particles
Exhaust Gases
*Vehicle Emissions
*Automobiles

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6.75

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EPA-650/2-74-065

ADVANCED PROTOTYPE DIRECT READING INSTRUMENT FOR PARTICULATE MASS MEASUREMENT

by

R. S. Lorenz, R. J. Pfeifer, D. E. Cressman

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Contract No. 68-02-0782
ROAP No. 26ACV
Program Element No. 1A1010

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Prepared for

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WASHINGTON, D.C. 20460

June 1974

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This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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1.0 INTRODUCTION AND SUMMARY

This report describes the work performed by Industrial Nucleonics Corporation (IN) on Contract No. 68-02-0782. The work comprised the further development and refinement of a direct-reading instrument for particulate mass measurement. The work was directed and supported by the Environmental Protection Agency.

The recent emphasis on creating and maintaining a clean and healthy environment has created the need for an instrument which can quickly and accurately monitor the volume of particulate matter being emitted by both stationary and mobile sources. In the case of mobile sources, sampling time is of the essence. Typically, the sources are monitored either at the end of a production line or in roadside vehicle checks. In either case, only a very limited amount of time is available for the collection of several samples (usually three samples). This means that the amount of particulate matter collected is typically in the microgram range and that the instrument used in measuring the quantity of particulate must be highly accurate. In the case of stationary sources, the work area is typically very dirty and crowded and is not very conducive to laboratory-type tests. For these reasons, a nucleonic particulate mass monitor is extremely attractive. Such a device provides a rapid, accurate measurement of very small quantities of particulate matter

collected on a filter and is portable and suitable for use in both mobile and stationary source measurements.

A prototype nucleonic particulate mass monitor was developed by Industrial Nucleonics Corporation under Contract No. 68-0-0210 in 1971. This device provided measurement accuracy (30 ± 10 micrograms per square centimeter resolution) that was unavailable from any other direct-reading particulate mass monitor. Certain features of the design, however, required modification in order to be compatible with all measurement requirements of the EPA. There were three principal problem areas. The most serious was the use of a Swirlmeter to measure flow rate through the filter. The Swirlmeter's design made necessary mounting of the flowmeter upstream of the filter where it occasionally caused erroneous particulate loadings. The other two areas of concern were the packaging of the unit, which required redesign to make it more easily portable; and the cassette transfer mechanism, which required redesign to make it compatible with the Federal Cycle specified for mobile sources.

The particulate monitor as redesigned is composed of three major submodules which enhance the operational flexibility and maintainability of the gauge. The submodules are (a) the computer unit, (b) the sampling unit, and (c) the flow unit. This arrangement provides for maximum ease in transporting and

reassembling the mass monitor as well as providing three functional blocks which aid in troubleshooting the monitor. The cassette transfer mechanism contained in the sampling unit has been drastically redesigned. The new mechanism allows compliance with new Federal Cycle requirements and allows for much more precise positioning of the cassette. This increased position precision improves the accuracy of the monitor by insuring that the section of filter observed during the precollection standardization period is the same filter section observed during the postcollection measurement. The final major change introduced to the unit is the inclusion of a mass flowmeter which automatically regulates the flow rate through the filter. Thus, as a filter becomes loaded with particulate matter, the differential pressure across the filter is increased in order to maintain the desired mass flow rate of air through it.

Preliminary tests with the particulate mass monitor have verified the accurate and automatic operation available with the device. Extensive tests conducted at Industrial Nucleonics with various filter materials have insured that sample collection and measurement are done in a manner consistent with meeting the required resolution of 30 ± 10 micrograms per square centimeter.

2.0 DEVELOPMENT

This section discusses in detail the changes that were made in both the electrical and mechanical designs of the particulate monitor in order to meet the measurement requirements called for by the EPA. The repackaging of the unit is adequately discussed in the Operation Manual, which is included with this report as Appendix B. The development description will therefore involve only the electrical, mechanical, and programming changes required for the new flow controller and the new cassette transfer mechanism.

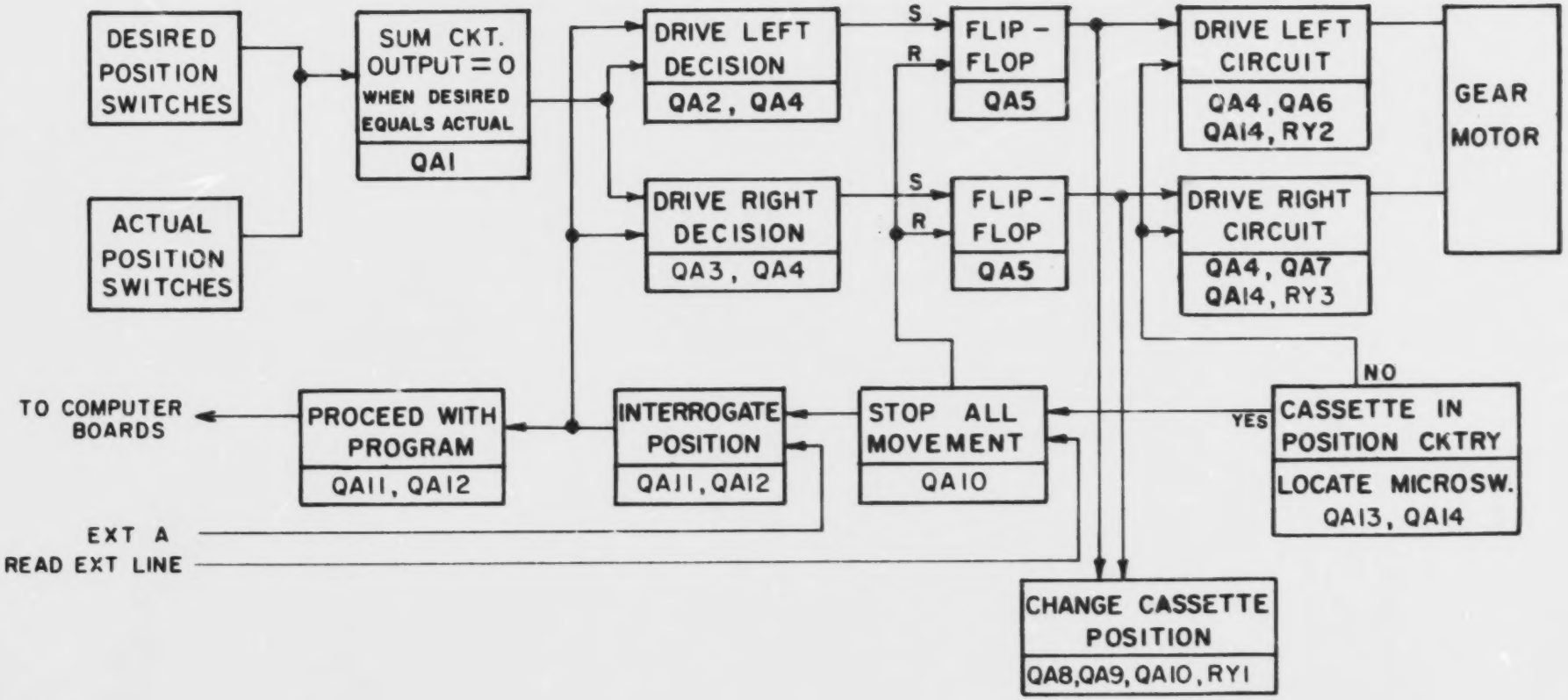
2.1 Electrical Design

A new cassette locator circuit was necessary in order to permit compliance with the Federal Cycle and in order to allow more precise location of the cassettes than was possible with the rotary solenoids used previously. The d.c. motor in combination with the gear and rack offered these advantages but the location control became more complex than was previously required. It was necessary with the gear and rack design to sense where the cassette was, and in which direction the motor should turn in order to reach the desired location. In order to assure positive precise location of the cassette, microswitches were used to provide both a coarse and a fine control over the position. Several microswitches were used to inform the locator electronics that the cassette was in the general desired area,

and a specific microswitch (called the Locate Microswitch) was used to precisely position the cassette.

In order to aid in understanding the new cassette locator electronics, a block diagram is included as Figure 1. A thorough understanding of the actual circuitry can only be attained by study of the actual schematic included as Figure 2. The blocks in the block diagram are laid out so that they correspond roughly to the position of the associated circuitry on the schematic. In addition each block shows the integrated circuits performing the function designated in that particular block.

In the upper left-hand corner are two blocks showing Desired and Actual Position switches. The Desired Position switches are solid-state switches which are energized by signals coming from the computer module. The Actual Position switches are three microswitches mounted on the cassette transfer mechanism and used for determining coarse position of the cassette. Each of these switches feeds a given amount of current into the summing circuit. The solid-state switches (Desired Position) provide positive input current while the microswitches provide negative input current. Thus, when the actual position corresponds to the desired position, the net current into the amplifier is zero. If the cassette is to be moved to the right (e.g., from the automatic load station to the measure station),



CASSETTE LOCATOR BLOCK DIAGRAM

Figure 1

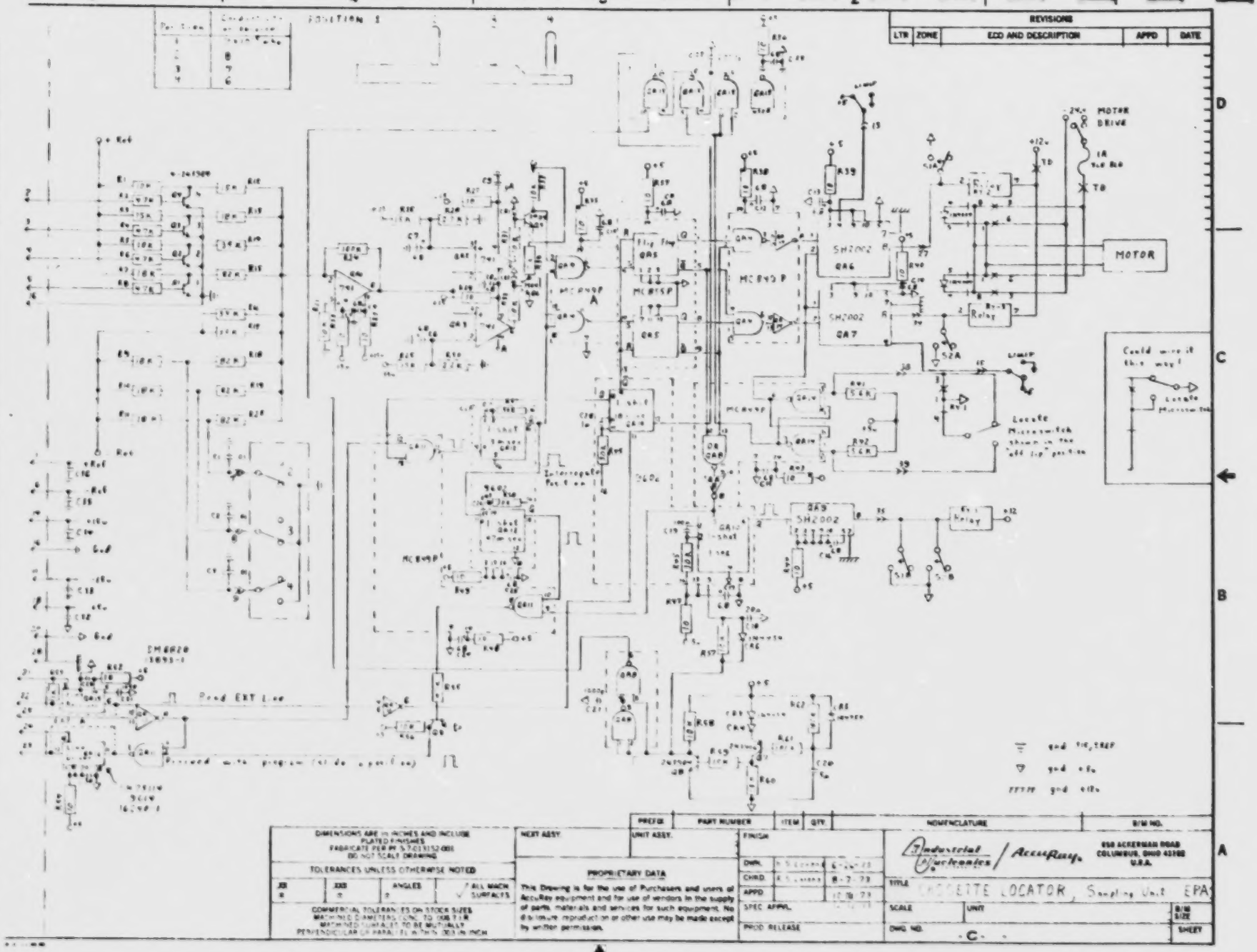

REVISIONS
LTR ZONE ECO AND DESCRIPTION APPD DATE
MOTOR
MOTOR DRIVE
MC8830P
SN2002
Relay
Could wire it this way?
Locate Microswitch shown in the cam position
Proceed with program (if do specified)
PREFIX PART NUMBER ITEM QTY NOMENCLATURE B/M NO.
DIMENSIONS ARE in INCHES AND INCLUDE PLATED FINISHES
FABRICATE PER PH 5.7.013152.001
DO NOT SCALE DRAWING
TOLERANCES UNLESS OTHERWISE NOTED
NEXT ASSY. UNIT ASSY.
FINISH
PROPRIETARY DATA
This Drawing is for the use of Purchasers and users of AccuRay equipment and for use of vendors in the supply of parts, materials and services for such equipment. No disclosure, reproduction or other use may be made except by written permission.
DWN. CHKD. APPD. SPEC APPVL. PROD RELEASE
Industrial Electronics / AccuRay
850 ACKERMAN ROAD COLUMBUS, OHIO 43202 U.S.A.
TITLE CASSETTE LOCATOR, Sampling Unit EPA
SCALE UNIT B/M SIZE
DWG NO. -C- SHEET

Figure 2. CASSETTE LOCATOR SCHEMATIC

Reproduced from best available copy.

the output of the summing circuit QA1 is negative by more than 2 volts. This causes a drive right decision to be made in QA3 and QA4. Conversely, if the cassette is to be moved to the left, the output of the summing circuit QA1 is positive and a drive left decision is made in QA2 and QA4. When the output of the summing circuit is zero, the cassette is approximately in the proper position. Precise positioning of the cassette is then achieved by means of the Locate Microswitch.

Even though the decision as to which direction to move the cassette is made by circuits QA2, QA3, and QA4, the decision cannot be implemented until the External A input line from the computer goes high (+ 5 ± 0.5 volts) and the Read External Line input from the computer has a pulse presented on it. The External A input indicates that the action desired by the computer is the movement of the cassette. The Read External Line input is a general signal going to all external functions indicating when some type of action is requested by the computer. When the External A line is high, it enables the Interrogate Position circuitry to accept Read External Line pulses. The Read External Line pulse enters the cassette locator circuitry and triggers a one-shot which then signals the Interrogate Position circuitry and enables the drive right or left decision to be implemented.

The Stop All Movement one-shot which is triggered by the Read External Line also resets flip-flops in integrated circuit QA5. These flip-flops should already have been reset when the cassette reached its last correct position. The Stop All Movement one-shot simply insures that there will be no previously set signals still resident in the flip-flop, which could potentially confuse the drive right or drive left decision. When the pulse comes out of the Interrogate Position circuitry and goes through the drive right or drive left decision, it then sets one of the two flip-flops if any cassette movement is necessary. These flip-flops then in essence remember that a decision to drive right or drive left was made and they will retain that decision until the Locate Microswitch is triggered again. The output of the flip-flop enables the appropriate drive circuitry which consists primarily of relay drivers and relays to turn the motor on.

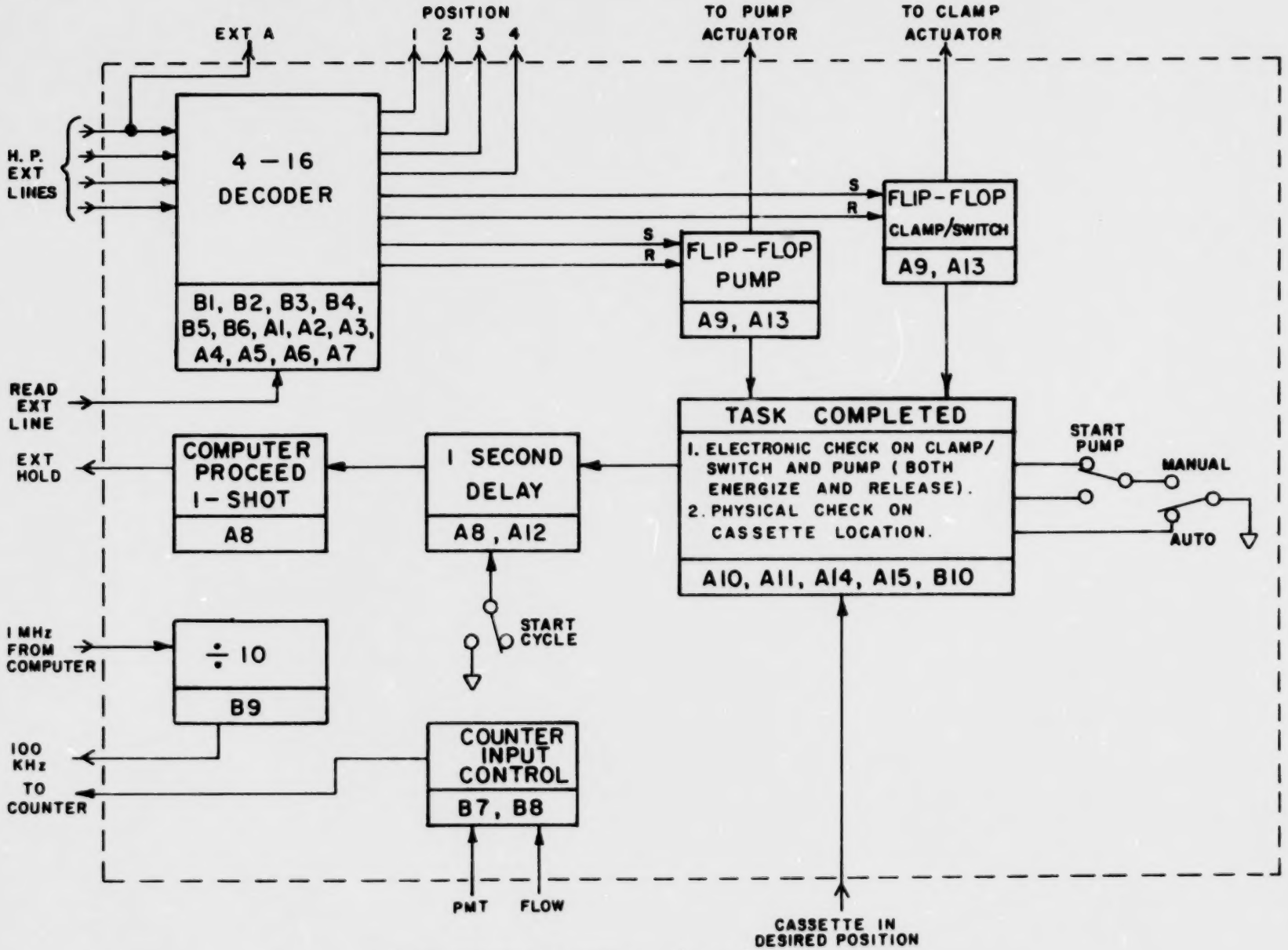
The flip-flops also trigger the Change Cassette Position circuitry. The function of this circuitry is only to override the Locate Microswitch which is still triggered since the cassette has not moved since it reached the last correct position. The Change Cassette Position circuitry energizes a relay which allows the drive right or drive left decision in the flip-flop to be input to the relays independent of the Locate Microswitch. This override function is only

present for one second after initiation of a cassette position change by the flip-flop. Therefore, after this one second, the Locate Microswitch again has control over the precise position of the cassette.

Once the Locate Microswitch is tripped, indicating that the cassette is in one of its four positions, the Stop All Movement one-shot is again triggered thus resetting the flip-flop and turning off the relay driver. The Stop All Movement one-shot then triggers the Interrogate Position circuitry. Thus, if a change of the cassette by more than one position were required, the circuitry would initially make a movement between two adjacent positions and stop at the first position that it reached. The Interrogate Position circuitry would then inform the flip-flop that further movement was necessary. The Change Cassette Position circuitry would again be triggered and movement would be continued to the next position where the Interrogate Position one-shot would again be triggered. Once the output of the summing circuit is zero and the Locate Microswitch indicates that the cassette is in the acceptable position, an output is issued from the Proceed with Program circuitry to the computer which indicates that the cassette is in the proper position for the next function to be performed by the program.

Both the cassette locator circuitry and the other external functions (such as the pump) require interface electronics between themselves and the HP computer. Therefore, another new set of boards in the design is the computer boards A and B shown in block diagram form in Figure 3. These boards act as an interface between the computer output lines and the external equipment which is to be actuated. The boards also act as an interface between the status indicators and the start cycle and start pump switches mounted in the computer module. The hardware controlled by the computer via these boards consists of the pump, the clamp, and the cassette transfer mechanism. The instruction from the computer specifying which equipment is to be energized and in what manner is output from the computer via a four-line code. This code must, therefore, be decoded in order to provide single-line instructions to the specific hardware to be actuated.

In addition to providing commands to the external equipment, the computer boards A and B also make checks to be certain that the clamp and pump are in the proper state and that the cassette is in the proper location prior to continuation of the program. Once these checks are completed, the computer boards A and B provide an output signal on the External Hold line to the computer indicating that the program should continue. There is a one-second delay inserted between



BLOCK DIAGRAM COMPUTER BOARDS A & B

Figure 3

completion of the check and continuation of the program in order to assure that all motion has reached a steady state prior to continuation of the program. After this one-second delay, the External Hold line is taken high to +5 volts for 23 microseconds.

These boards also make use of a 1 megahertz square wave signal from the computer and generate from it a 100 kilohertz square wave signal which is used in the flowmeter's voltage-to-frequency converter. The final function of thes boards is to switch the input for the HP counter from the photomultiplier tube to the flow count rate and back again at the appropriate times in the program.

The complete schematic for these boards is included in Appendix B of the Operation Manual.

2.2 Mechanical Design

The major changes implemented in the mechanical area were the utilization of a Hastings flow controller, development of a rack/gear driven cassette transfer mechanism, redesign of the cassette, and repackaging of the hardware. The first element of mechanical design was the replacement of the Swirlmeter previously used for flow measurements with a Hastings mass flowmeter and controller. The Swirlmeter previously used could not be mounted next to the pump since its accuracy suffered considerably when exposed to the oscillatory air flow produced by the pump. It was therefore used upstream of the

filter, where it could potentially influence the particulate concentration, thus causing inaccurate measurement results. In addition, it was incapable of providing control over the flow in order to compensate for different filter media and loading of the filter. The Hastings flowmeter incorporated into the instrument with the new design provided accurate mass flow readings even when mounted next to the pump and past the collection filter and also provided automatic control over the flow. A complete description of the gas flow system is included in the Operation Manual.

The previous cassette transfer mechanism made use of rotary solenoids and was capable only of Single Cycle operation. This design did not provide repeatable or reliable positioning of the cassette and was totally unacceptable for Federal Cycle operation. The new cassette transfer mechanism makes use of a motor driven gear rack mounted to the transfer slide and suspended on the base plate by means of Schneeburger rollers. A bar with cams on it is mounted to the transfer slide in order to actuate both the coarse microswitches and the Locate Microswitch.

The cassette design itself was called out in the contract to have an overall filter diameter of 25 millimeters. The collection area was to be 3 square centimeters corresponding to a filter spot size of 20 millimeters diameter. However, during the course of the program, the EPA requested that the

gauge be designed to provide a second larger filter spot size capability in addition to the 20 millimeter size. The overall filter diameter was changed to 37 millimeters in order to accommodate the additional larger spot size. As finally delivered, the cassettes make use of 37 millimeter diameter filters and provide a 20 millimeter spot size. Additional filter scrims which provide a 28 millimeter diameter spot size were also delivered. The cassettes themselves are 50.3 millimeters diameter. This is an increase of 0.3 millimeters over the 50 millimeters specified in the contract and was designed as such in order to minimize the amount of free play in the positioning of the cassette within the pocket of the transfer mechanism.

During testing of the particulate mass measurement instrument, it became apparent that all edges, both of the transfer mechanism and of the cassette, must be beveled in order to assure freedom from jamming of the mechanism. These edges were subsequently all beveled and jamming of the mechanism was virtually eliminated. A complete description of the operation of the transfer mechanism and the various controls and features exhibited by it is given in the Operation Manual.

2.3 Programming Changes

The principal programming changes were caused by the necessity to operate either in Single Cycle or in Federal Cycle

mode. The programming capacity of the HP computer is not large enough to allow the program for both cycles to be resident simultaneously. Therefore, the pumping cycle control which constitutes the major change between the cycles is contained in the first two program boards while subroutines for counting and mass calculations are contained in the last three program boards. In addition, for the Single Cycle, the first two boards contain the programming necessary to print out the total volume flow through the filter and the particulate concentration derived from that flow. For the Federal Cycle these first two boards contain the programming required to compute the particulate concentration based on the equation contained in the Federal Register. Maximum usage has been made of common subroutines which can be referred to and used repeatedly in order to generate the most efficient program possible. Although the exact programming forms are contained in the Operation Manual, Figure 4 contains a flow diagram for the Single Cycle and Figure 5 contains a flow diagram for the Federal Cycle. The flow diagrams are referenced by means of address numbers to the specific programming forms contained in the Operation Manual.

Figure 4

SINGLE CYCLE
FLOW DIAGRAM
Page 1/3

NOTE:

Number in the lower right-hand corner of each block refers to the address in the program at which the function in the block is begun.

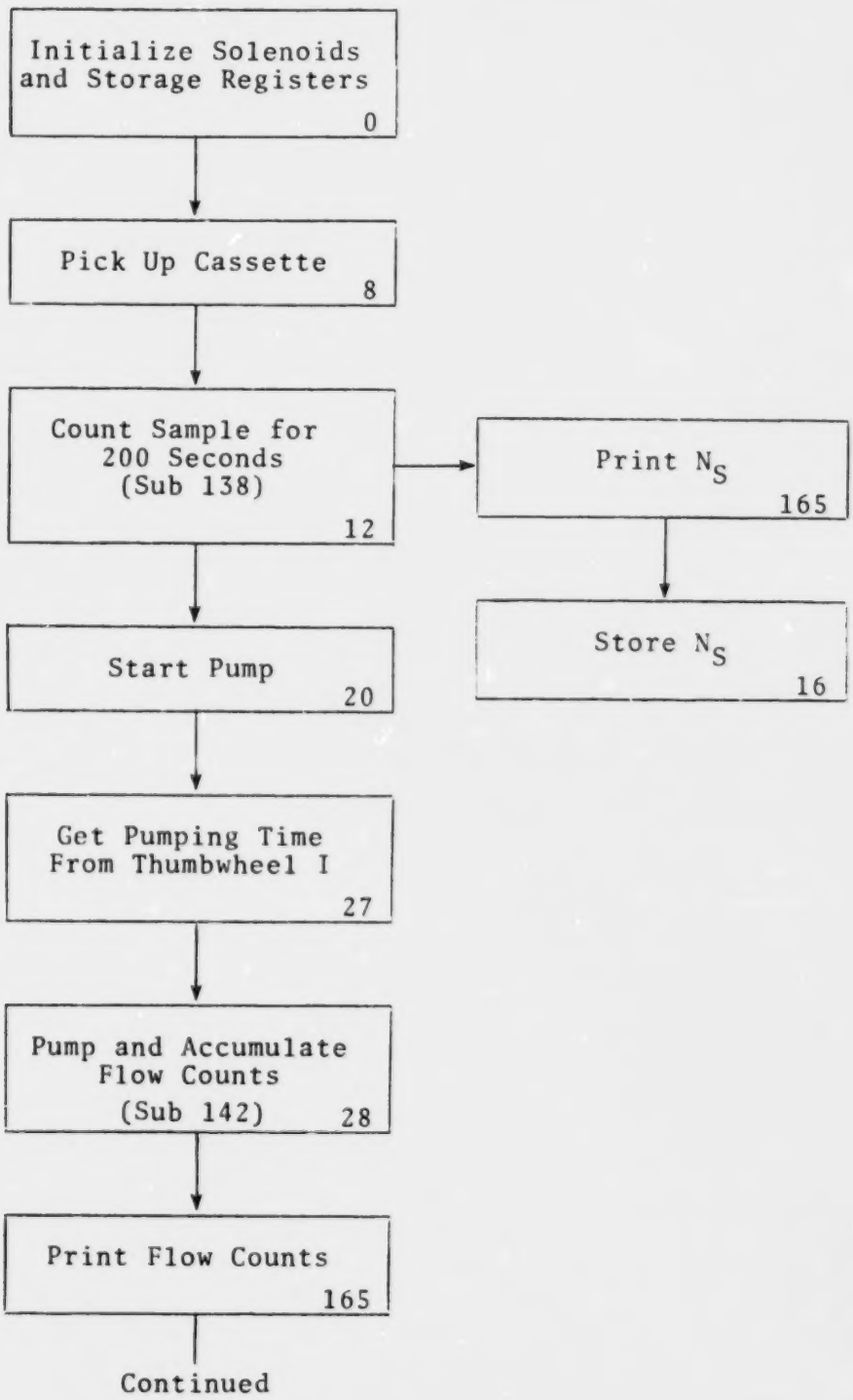


Figure 4

Page 2/3

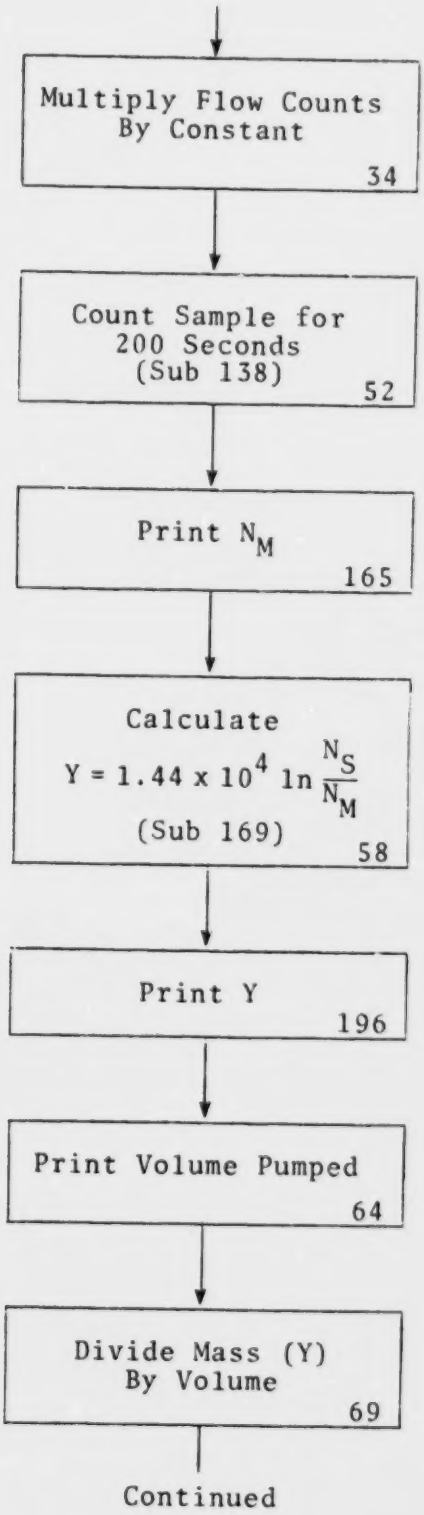


Figure 4

Page 3/3

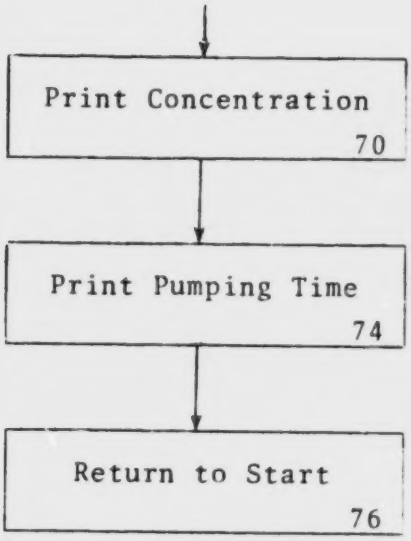


Figure 5

FEDERAL CYCLE
FLOW DIAGRAM
Page 1/4

NOTES:

1. Number in the lower right-hand corner of each block refers to the address in the program at which the function in the block is begun.

2. This flow chart assumes that the first two thumbwheels were set at 505 and 866 seconds, respectively.

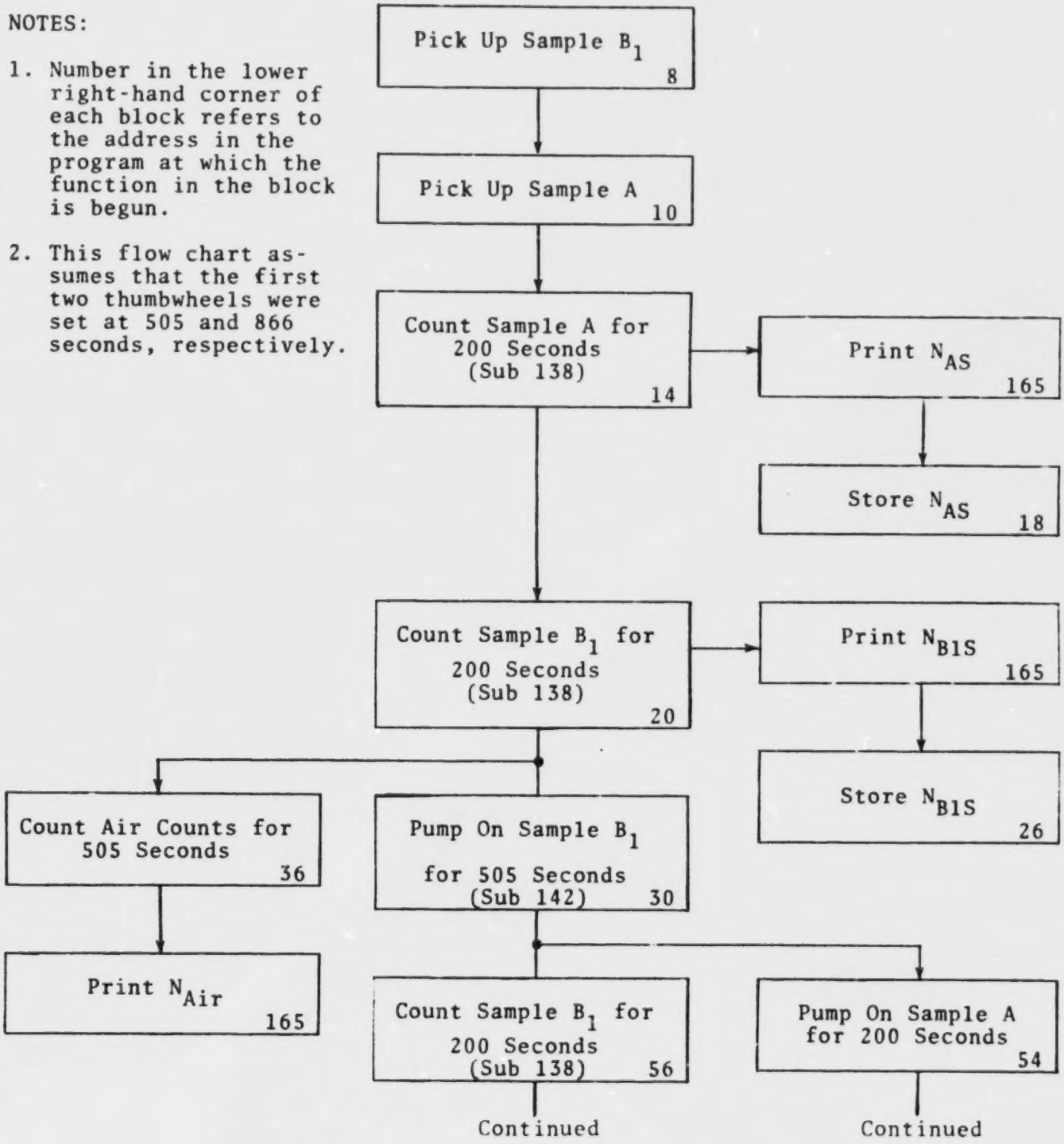

Pick Up Sample B_1 8
Pick Up Sample A 10
Count Sample A for 200 Seconds (Sub 138) 14
Print N_{AS} 165
Store N_{AS} 18
Count Sample B_1 for 200 Seconds (Sub 138) 20
Print N_{B1S} 165
Store N_{B1S} 26
Count Air Counts for 505 Seconds 36
Print N_{Air} 165
Pump On Sample B_1 for 505 Seconds (Sub 142) 30
Count Sample B_1 for 200 Seconds (Sub 138) 56
Pump On Sample A for 200 Seconds 54
Continued
Continued

Figure 5

Page 2/4

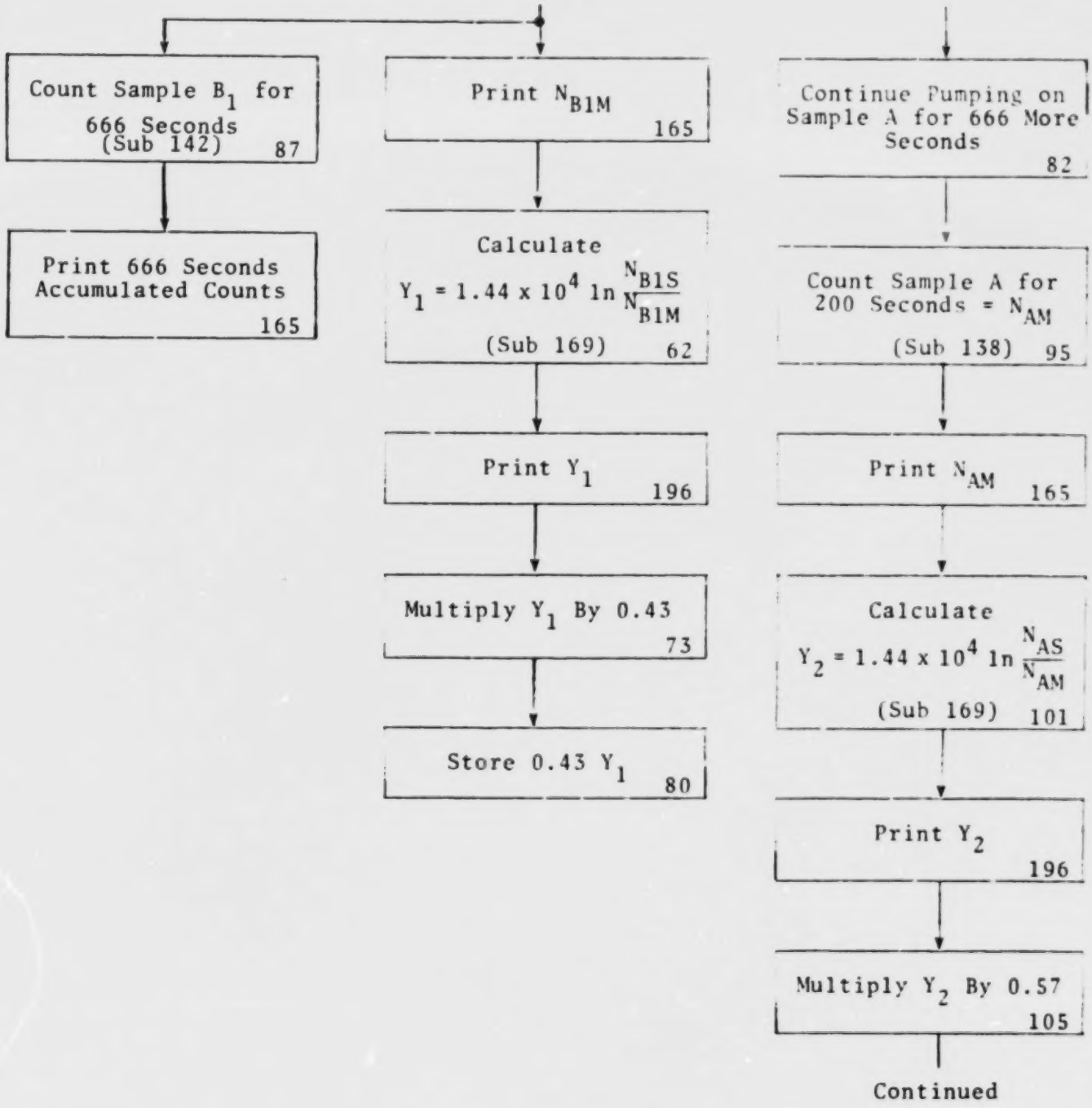

Count Sample B_1 for 666 Seconds (Sub 142) 87
Print 666 Seconds Accumulated Counts 165
Print N_{B1M} 165
Calculate $Y_1 = 1.44 \times 10^4 \ln \frac{N_{B1S}}{N_{B1M}}$ (Sub 169) 62
Print Y_1 196
Multiply Y_1 By 0.43 73
Store 0.43 Y_1 80
Continue Pumping on Sample A for 666 More Seconds 82
Count Sample A for 200 Seconds = N_{AM} (Sub 138) 95
Print N_{AM} 165
Calculate $Y_2 = 1.44 \times 10^4 \ln \frac{N_{AS}}{N_{AM}}$ (Sub 169) 101
Print Y_2 196
Multiply Y_2 By 0.57 105
Continued

Figure 5

Page 3/4

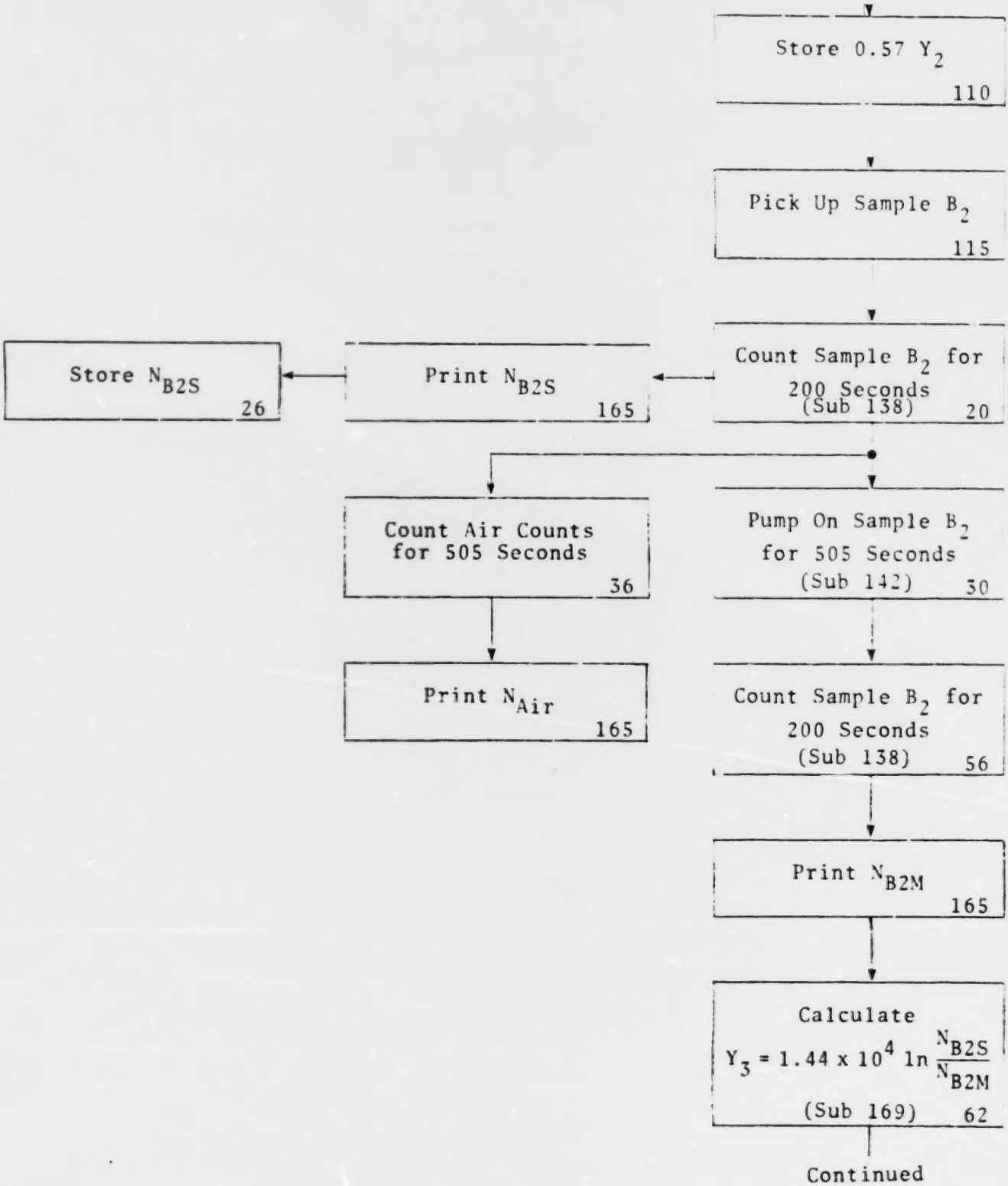
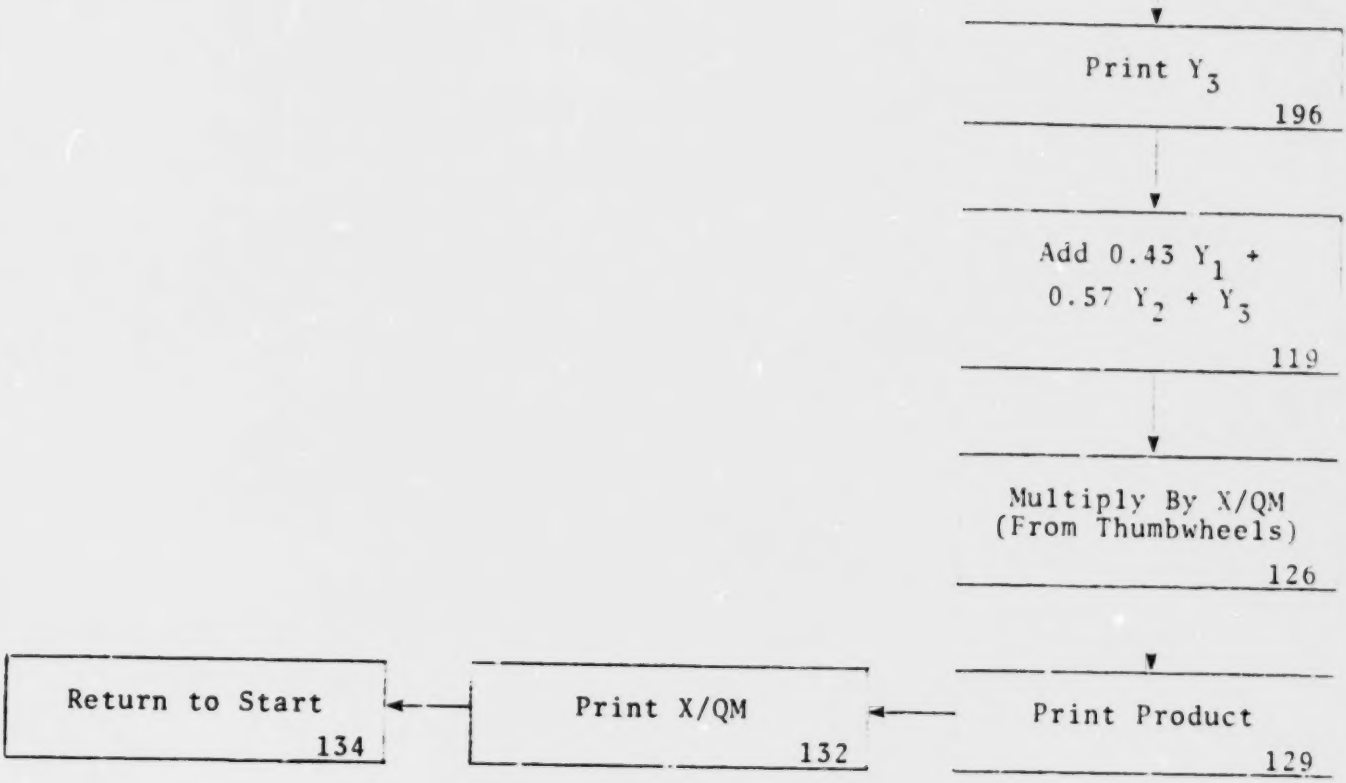

Store 0.57 Y_2
110
Pick Up Sample B_2
115
Count Sample B_2 for 200 Seconds (Sub 138) 20
Store N_{B2S} 26
Print N_{B2S} 165
Count Air Counts for 505 Seconds 36
Print N_{Air} 165
Pump On Sample B_2 for 505 Seconds (Sub 142) 30
Count Sample B_2 for 200 Seconds (Sub 138) 56
Print N_{B2M} 165
Calculate $Y_3 = 1.44 \times 10^4 \ln \frac{N_{B2S}}{N_{B2M}}$ (Sub 169) 62
Continued

Figure 5

Page 4/4



3.0 TESTS

A series of tests were conducted on the new particulate mass measurement instrument with the objective of first verifying proper operation and then calibrating the instrument. These tests were performed both at Industrial Nucleonics Corporation and at the EPA laboratories in Research Triangle Park. Tests performed at Industrial Nucleonics were generally the check out and preliminary calibration tests, and those performed at the EPA consisted of additional calibration and tuning of the instrument, although the EPA tests were inconclusive due to problems encountered. Detailed test data are presented in Appendix A.

3.1 Predelivery Tests

The first tests conducted at Industrial Nucleonics were repeatability tests wherein no mass was collected on the filter but the cassette was moved throughout the entire transfer cycle so that the computed mass should have been zero in all of these tests. Although this was not the case initially, two corrective measures were taken to insure repeatable locating of the cassette. The first corrective action was repositioning of the Locate Microswitch so that it was only tripped at the extreme height of the actuator cam. If the arm on the switch were located too close to the shoulder on which the cam was mounted, the position of the transfer mechanism at which the switch was tripped would depend upon the direction in which

the mechanism were traveling. The repeatability tests, therefore, pointed up a need for precise adjustment of the Locate Microswitch position. The second corrective action was the enlargement of the cassette size from 50.0 to 50.3 millimeters diameter. This insured that the cassette fit snugly in the pocket of the transfer mechanism and was not able, therefore, to attain different positions depending upon the direction of travel of the mechanism. Repeatable positioning of the cassette was critical because the filter media was not 100 percent uniform, and in fact some filter media contained holes surrounded by filter material (such as the Pallflex filter media). Since the source detector arrangement used in the mass measurement instrument was extremely sensitive to the total mass present between the source and the detector, any slight variation in the positioning of such nonuniform filters resulted in a measurement error.

The second problem encountered during the IX series of tests was the bowing of the filter media during the pumping cycle. Since the filters were very efficient at collecting particulate matter, they presented a large impedance to air flow and, therefore, a large differential pressure could be built up across the filter, particularly as the filter became loaded with particulate matter. This bowing down of the filter media caused a measurement error due to a geometry change in the filter between the standardize measurement and the after-

collection measurement. In order to overcome this problem, the scrim mounted below the filter was raised so that when the solenoid clamped the cassette into position, the scrim was brought up into contact with the filter media. This then supported the filter during the pumping and prevented any distortion of the surface thus eliminating the measurement error.

Repeatability test results are summarized in Table I from the data of Appendix A. The first series of tests, performed immediately after fabrication was completed, showed significant errors in the average and standard deviation of the zero mass repeatability measurements. The second series of tests, performed after adjustment of the Locate Microswitch position and increase of the cassette diameter, showed improvement. The third series of tests, conducted after the scrim was modified to prevent filter bowing indicated good zero mass repeatability, with average values of 2 $\mu gm/cm^2$ or less with the pump disconnected and 11 $\mu gm/cm^2$ or less with the pump connected, and standard deviation of less than 11 $\mu gm/cm^2$. This performance appears to meet the minimum sensitivity specification of 30 ± 10 $\mu gm/cm^2$. In all cases, performance with the pump connected was inferior to that with the pump disconnected, probably due to actual small filter mass changes produced by the passage of gas through the filter.

TABLE I. SUMMARY OF FIRST, SECOND, THIRD TEST SERIES

Average Mass Density and Standard Deviation
for Zero Mass Repeatability Tests

Pump Disconnected

Series / Filter	1	2	3
Gelman A	11/48	8/14	1/9
Nuclepore		3/4	2/9
Pallflex			1/5
Millipore H95E	12/22		2/5

Pump Connected

Series / Filter	1	2	3
Gelman A	3/51	17/35	11/11
Nuclepore			
Pallflex			4/7
Millipore H95E	8/32		6/6

NOTE--Data presented: Ave. Mass Density/σ, units $\mu gm/cm^2$

Series 1: Gauge as initially fabricated.

Series 2: Alignment of Locate Microswitch and increase of cassette diameter implemented.

Series 3: Scrim redesign implemented.

After changing the scrim design to prevent bowing of the filter, it was necessary to conduct scrim tests in order to insure that the crossbars used in the supporting scrim structure for the 28 millimeter spot size did not cause segregation of the flow. In order to insure accurate measurement results, it was essential that the particulate matter be collected on the filter in a uniform manner and not be concentrated in certain areas with no particulate matter being present in other areas within the spot size. Therefore, a series of experiments was conducted with various scrim structures in order to determine the effect on the gas flow. No significant effect was found from any of the scrims and the supporting scrim structure was, therefore, considered to be acceptable.

As has been consistently pointed out, any particulate mass measurement instrument is sensitive to moisture collected on the filter. This problem was a persistent one during the tests but one for which there was no solution and which was not able to be quantified due to an inability to conduct controlled moisture experiments. This moisture problem is the most severe problem requiring solution in all sampling systems and will, of course, be extremely important in the measurement of auto exhausts.

A fourth problem arose during these tests due to the interaction of the magnetic field of the solenoid on the gain of the photomultiplier tube. Although this could potentially have

been a problem on the first mass measurement instrument delivered, it never arose because the solenoid was never actuated at the same time that measurements were being made with the photomultiplier tube. However, in order to accommodate the Federal Cycle, it was necessary that measurements with the photomultiplier tube be made simultaneously with a pumping cycle. It was then noted that the PMT's gain was seriously effected whenever the solenoid was activated. This problem required that a mu-metal shield be installed around the photomultiplier tube to shield the tube from the magnetic field. In addition, magnetic isolators were installed on the solenoid mounting pads in order to break the magnetic path and provide further insurance that the field could not be coupled into the photomultiplier tube. With these corrections the tube was stable during all pumping and nonpumping cycles of the instrument.

After all of these preliminary tests had been completed, sensitivity tests were conducted in order to determine the calibration constant that was to be entered into the program. Data were obtained with the use of cigarette smoke blown into the input port of the sampling unit and then collected on the filter. Collected sample sizes varied from 1.0 up to 6.0 milligrams. Accurate sampling and flow distributions required mixing of the cigarette smoke with input air, and the testing configuration derived is shown in Figure 6. Since information at that time was that the EPA was going to be using the H95E filter media,

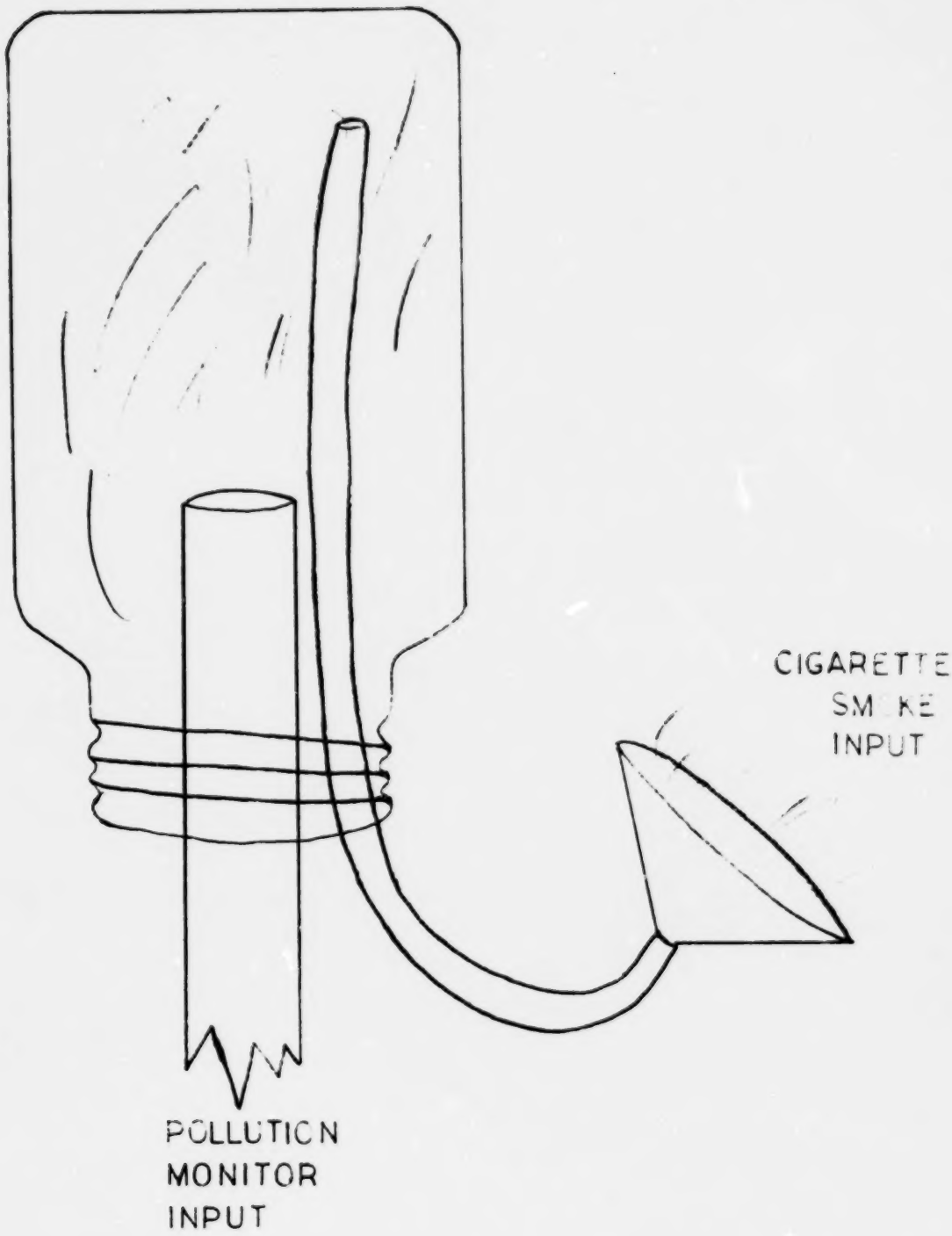


FIGURE 6 SMOKE SAMPLING SYSTEM

the calibration constant was changed so that the unit was calibrated with H95E material. Subsequent tests and calibration utilizing the cigarette smoke indicated that proper calibration had been achieved and that the gauge was accurately and repeatedly measuring the collected mass (see Data--Fourth Test Series).

3.2 EPA Tests

After the particulate mass measurement instrument was delivered to the EPA in late January 1974, a series of tests was conducted with machine-generated fluorescein aerosol. Two significant problems were encountered during the tests which resulted in a considerable amount of time being devoted to identifying their source. After these problems were identified, however, and corrective measures taken, the instrument produced reliable, accurate mass measurement results (see Data--Fifth Test Series).

The first of the problems arose from the extremely sensitive balance against which the instrument was being compared. The EPA balance was capable of measurements with ±1 microgram accuracy. As such it was extremely sensitive to any loss or gain in moisture during transport from the instrument to the scale and in fact even during weighing of the filter itself. Several hundred micrograms of change could be seen over as short a period as five minutes. Since most of the samples being obtained were less than 1,000 micrograms total, this change in weight due to moisture was extremely critical. The only semiacceptable resolution of this problem was reduction of

the time between when the filter was ejected from the instrument and when it was weighed on the balance.

The second problem observed was that the aerosol tended to collect not only within the spot size area defined by the scrim but also around the outside perimeter of the filter. The amount of material collected outside the spot size was not repeatable and did not appear to be linear as a function of the amount of time that a filter was pumped on. This material clearly caused measurement error since it was weighed by the balance but not sensed by the source-detector measurement system. Several different attempts to correct this problem were tried. These included increasing the spot size in order to increase the area in which uniform collection occurred. This, however, was not particularly successful in reducing the error. The second attempt made was to raise the scrim so that it was in closer contact with the filter during the sampling time. This too was not successful in eliminating the particulate matter collected at the outer edge of the filter. The third technique was the use of a plastic guard ring placed on top of the filter with a hole in the center corresponding to the spot size. This technique was extremely successful in reducing and in fact eliminating particulate matter collection outside of the spot size. The use of the guard ring, however, was not acceptable for other experiments to be ultimately performed with the filters and, in addition, the guard rings occasionally got into the source beam and influenced very dramatically the

mass measurement obtained by the instrument. The resolution of this problem, therefore, was that the scrim was to be left as high as possible and the 20 millimeter scrim was to be used. The error was then minimized as much as possible and calibration was accomplished in this manner.

Preliminary calibration and test results are summarized in Table II from the data of Appendix A. The fourth series of tests was conducted at IN with a variety of filters and tobacco smoke as the calibration particulate. For each measurement, the gauge mass reading was compared with a balance reading, and the error (and standard deviation of a number of tests) computed from the difference. These deviations ranged from 39 to 65 $\mu gm/cm^2$. The fifth series of tests was conducted at the EPA laboratories, Research Triangle Park, North Carolina, with fluorescein aerosol as the calibration particulate. Utilization of a guard ring on the cassette, which inhibited diffusion of the particulate across an undefined area of the filter, provided a deviation of only 15 $\mu gm/cm^2$. Thus the gauge appears inherently capable of meeting specifications for the maximum particulate detection limit ($2,000 \pm 50$ $\mu gm/cm^2$) with excellent accuracy throughout the measurement range; aerosol and filter characteristics provide the practical limitation on realizable accuracy.

The only other problem encountered during the test was occasional jamming of the transfer mechanism with some cassettes. It was agreed that this problem would be handled through

TABLE II. SUMMARY OF FOURTH, FIFTH TEST SERIES

Number of Calibration Tests and Standard Deviation for Calibration Tests

Series	4	5
Filter		
Pallflex	10/61 µgm cm^{-2}	
Gelman A	5/49 µgm cm^{-2}	
H95E	7/65 µgm cm^{-2}	6/37 µgm cm^{-2}
H95E Federal Cycle	7/39 µgm cm^{-2}	
H95E with Guard Ring		9/15 µgm cm^{-2}

NOTE--Data Presented: Number of Tests/σ

Series 4: Calibration on cigarette smoke at IN

Series 5: Calibration on fluorescein aerosol at EPA

two approaches. All cassette edges were beveled in order to insure good passage through the transfer mecahnism. Secondly, a slip clutch was provided so that if any jamming did occur, no part of the rack or gear would be damaged.

4.0 SUMMARY AND CONCLUSIONS

On this contract the Particulate Mass Measurement Instrument was redesigned to improve collecting efficiency, simplify handling, and provide compatability with the new Federal Cycle requirements. The measurement system is the same one previously delivered on the initial contract and provides accuracy unachievable by other instruments. The redesigned instrument is more portable, more reliable, and completely compatible with all auto exhaust requirements as specified by the EPA. This device provides a means by which field measurements of both stationary and mobile sources of particulate pollution may be accurately monitored on a real-time, accurate basis. As such, the improvement generated in this design provides a significant step forward in the area of particulate monitoring.

APPENDIX A

PRELIMINARY INSTRUMENT TEST AND CALIBRATION DATA

The following data contain gauge mass readings as actually printed out with the initial IN calibration for the large scrim. Since the area measured by the source-detector combination is less than either the small spot size or the large spot size, the gauge has no way of determining whether the scrim size is large or small. Therefore, the calibration constant in the computer program must be changed along with the scrim. For the initial tests this was not done. Appropriate data tables therefore have a summary at the bottom of each table which corrects the average mass and standard deviation for the small scrim.

DATA--FIRST TEST SERIES

Conditions

1. Gauge as fabricated
2. Single Cycle operation mode
3. Repeatability tests--no mass collected
4. Pump disconnected, 15 second pump time
5. 20 millimeter scrim
6. Gelman Type A filter

Date	Test	Gauge Mass[a] (μgm)
13 November 1973	A	69
13 November 1973	B	65
13 November 1973	C	708
13 November 1973	D	693
13 November 1973	E	64
13 November 1973	F	635
13 November 1973	G	87
13 November 1973	H	-96
13 November 1973	I	12
13 November 1973	J	-281
13 November 1973	K	5
13 November 1973	L	55
13 November 1973	M	-31
13 November 1973	N	-68
13 November 1973	O	-483
13 November 1973	P	-57
13 November 1973	Q	-147
13 November 1973	R	-2
13 November 1973	S	131
13 November 1973	T	4

Ave. Mass = 68.2 μgm[a]
σ = 289.5 μgm

a) Gauge mass values shown are actual output values with initial IN calibration (for large scrim). Corrected values should reflect division by 2 (to convert to small scrim) and by 3 cm^2 (to convert to mass density).

Ave. Mass = 34.1 μgm
σ = 144.7 μgm

Ave. Mass Density = 11.4 $\mu gm/cm^2$
σ = 48.2 $\mu gm/cm^2$

DATA--FIRST TEST SERIES

Conditions

1. Gauge as fabricated
2. Single Cycle operation mode
3. Repeatability tests--no mass collected
4. Pump disconnected; 15 second pump time
5. 20 millimeter scrim
6. Millipore filter

Date	Test	Gauge Mass[a] (μgm)
13 November 1973	W	-28
13 November 1973	X	16
13 November 1973	Y	369
13 November 1973	Z	32
13 November 1973	AA	82
13 November 1973	AB	181
13 November 1973	AC	3
13 November 1973	AD	-12
13 November 1973	AE	-9
13 November 1973	AF	-12
13 November 1973	AG	-1
13 November 1973	AI	-20
13 November 1973	AJ	396
13 November 1973	AK	320
13 November 1973	AL	27
13 November 1973	AM	35
13 November 1973	AN	39
13 November 1973	AO	-60
15 November 1973	BA	62

Ave. Mass = 74.7 μgm[a]
σ = 129.6 μgm

a) Gauge mass values shown are actual output values with initial IN calibration (for large scrim). Corrected values should reflect division by 2 (to convert to small scrim) and by 3 cm^2 (to convert to mass density).

Ave. Mass = 37.3 μgm
σ = 64.8 μgm

Ave. Mass Density = 12.4 $\mu gm/cm^2$
σ = 21.9 $\mu gm/cm^2$

DATA--FIRST TEST SERIES

Conditions

1. Gauge as fabricated
2. Single Cycle operation mode
3. Repeatability tests--no mass collected
4. Pump connected, 9 second pump time
5. 20 millimeter scrim
6. Gelman Type A filter

Date	Test	Gauge Mass[a] (μgm)
13 November 1973	U	232
13 November 1973	V	628
15 November 1973	BI	-97
15 November 1973	BJ	-996
15 November 1973	BK	120
15 November 1973	BL	-26
15 November 1973	BM	-5
15 November 1973	BN	-52
15 November 1973	BO	-32
15 November 1973	BP	-73
15 November 1973	BQ	-55
15 November 1973	BR	-326
15 November 1973	BS	7
15 November 1973	BT	344
15 November 1973	BU	24
15 November 1973	BW	104
15 November 1973	BZ	155
15 November 1973	CD	-432
15 November 1973	CE	-38
15 November 1973	CF	174
15 November 1973	CG	423
15 November 1973	CH	183
15 November 1973	CI	92

Ave. Mass = 15.4 μgm[a]
σ = 307.2 μgm

a) Gauge mass values shown are actual output values with initial IN calibration (for large scrim). Corrected values should reflect division by 2 (to convert to small scrim) and by 3 cm^2 (to convert to mass density).

Ave. Mass = 7.7 μgm
σ = 153.6 μgm

Ave. Mass Density = 2.9 μgm/cm^2
σ = 51.2 μgm/cm^2

DATA--FIRST TEST SERIES

Conditions

1. Gauge as fabricated
2. Single Cycle operation mode
3. Repeatability tests--no mass collected
4. Pump connected, 9 second pump time
5. 20 millimeter scrim
6. Millipore filter

Date	Test	Gauge Mass[a] (μgm)
13 November 1973	AH	88
14 November 1973	AP	76
14 November 1973	AQ	-1
14 November 1973	AR	80
14 November 1973	AS	391
14 November 1973	AT	425
14 November 1973	AU	87
14 November 1973	AV	191
14 November 1973	AW	105
14 November 1973	AX	-376
14 November 1973	AY	-186
14 November 1973	AZ	-360
15 November 1973	BB	60
15 November 1973	BC	11
15 November 1973	BD	22
15 November 1973	BE	71
15 November 1973	BF	59
15 November 1973	BG	87
15 November 1973	BH	85

Ave. Mass = 48.2 μgm[a]
σ = 191.7 μgm

a) Gauge mass values shown are actual output values with initial IN calibration (for large scrim). Corrected values should reflect division by 2 (to convert to small scrim) and by 3 cm^2 (to convert to mass density).

Ave. Mass = 24.1 μgm
σ = 95.8 μgm

Ave. Mass Density = 8.0 μgm/cm^2
σ = 31.9 μgm/cm^2

DATA--SECOND TEST SERIES

Conditions

1. Fabricated gauge modified:
   a. Accurate Locate Microswitch positioning
   b. Cassette diameter increased to 50.3 millimeters
2. Single Cycle operation mode
3. Repeatability tests--no mass collected
4. 20 millimeter scrim
5. Gelman Type A filter

Date	Test	Pump Status	Gauge Mass[a] (µgm)
17 November 1973	CJ	15 Sec., Discon.	16
17 November 1973	CK	15 Sec., Discon.	92
17 November 1973	CL	15 Sec., Discon.	194
17 November 1973	CM	15 Sec., Discon.	152
17 November 1973	CN	15 Sec., Discon.	-81
17 November 1973	CO	15 Sec., Discon.	55
19 November 1973	CR	15 Sec., Discon.	-26
19 November 1973	CS	15 Sec., Discon.	86
19 November 1973	CT	15 Sec., Discon.	-69
19 November 1973	CU	15 Sec., Discon.	132
19 November 1973	CV	15 Sec., Discon.	107
19 November 1973	CW	15 Sec., Discon.	84
19 November 1973	CX	15 Sec., Discon.	69
19 November 1973	CY	15 Sec., Discon.	-135
19 November 1973	CZ	15 Sec., Discon.	69
19 November 1973	DA	15 Sec., Discon.	-17
21 November 1973	DP	15 Sec., Discon.	96
		Ave. Mass =	48.5 µgm[a]
		σ =	84.0 µgm
17 November 1973	CP	15 Sec., Con.	183
19 November 1973	CQ	15 Sec., Con.	199
19 November 1973	DB	15 Sec., Con.	-274
19 November 1973	DG	15 Sec., Con.	68
21 November 1973	DQ	15 Sec., Con.	91
21 November 1973	DR	15 Sec., Con.	56
21 November 1973	DS	15 Sec., Con.	714

Continued

Date	Test	Pump Status	Gauge Mass[a] (μgm)
21 November 1973	DT	15 Sec., Con.	53
21 November 1973	DU	15 Sec., Con.	65
4 December 1973	DV	15 Sec., Con.	68
4 December 1973	DW	15 Sec., Con.	-1
4 December 1973	DX	15 Sec., Con.	77
4 December 1973	DY	15 Sec., Con.	7

Ave. Mass = 100.5 μgm[a]
σ = 207.5 μgm

a) Gauge mass values shown are actual output values with initial IN calibration (for large scrim). Corrected values should reflect division by 2 (to convert to small scrim) and by 3 cm^2 (to convert to mass density).

Pump Disconnected

Ave. Mass = 24.2 μgm
σ = 42.0 μgm

Ave. Mass Density = 8.1 μgm/cm^2
σ = 14.0 μgm/cm^2

Pump Connected

Ave. Mass = 50.2 μgm
σ = 103.7 μgm

Ave. Mass Density = 16.7 μgm/cm^2
σ = 34.6 μgm/cm^2

DATA--SECOND TEST SERIES

Conditions

1. Fabricated gauge modified:
   a. Accurate Locate Microswitch positioning
   b. Cassette diameter increased to 50.3 millimeters
2. Single Cycle operation mode
3. Repeatability tests--no mass collected
4. 20 millimeter scrim
5. Nuclepore filter

Date	Test	Pump Status	Gauge Mass[a] (μgm)
20 November 1973	DE	9 Sec., Discon.	-37
20 November 1973	DF	9 Sec., Discon.	41
20 November 1973	DH	9 Sec., Discon.	-52
20 November 1973	DJ	9 Sec., Discon.	-1
20 November 1973	DK	9 Sec., Discon.	-14
20 November 1973	DL	9 Sec., Discon.	-57
20 November 1973	DM	9 Sec., Discon.	-31
20 November 1973	DN	9 Sec., Discon.	-42
20 November 1973	DO	9 Sec., Discon.	10
		Ave. Mass =	-20.3 μgm[a]
		σ =	21.7 μgm
20 November 1973	DG	9 Sec., Con.	124

a) Gauge mass values shown are actual output values with initial IN calibration (for large scrim). Corrected values should reflect division by 2 (to convert to small scrim) and by 3 cm^2 (to convert to mass density).

Pump Disconnected

Ave. Mass = -10.1 μgm
σ = 10.8 μgm

Ave. Mass Density = -3.4 $\mu gm/cm^2$
σ = 3.6 $\mu gm/cm^2$

DATA--THIRD TEST SERIES

Conditions

1. Fabricated gauge modified
   a. Accurate Locate Microswitch positioning
   b. Cassette diameter increased to 50.3 millimeters
   c. Scrim modified to prevent filter deflection
2. Single Cycle operation mode
3. Repeatability tests--no mass collected
4. 20 millimeter scrim
5. Gelman Type A filter

Date	Test	Pump Status	Gauge Mass[a] (μgm)
11 December 1973	EF	30 Sec., Discon.	28
11 December 1973	EG	30 Sec., Discon.	28
11 December 1973	EJ	30 Sec., Discon.	-10
11 December 1973	EM	30 Sec., Discon.	-31
11 December 1973	EU	30 Sec., Discon.	-41
13 December 1973	EV	30 Sec., Discon.	-109
13 December 1973	EW	30 Sec., Discon.	118
13 December 1973	EX	30 Sec., Discon.	94
13 December 1973	EY	30 Sec., Discon.	-50
13 December 1973	EZ	30 Sec., Discon.	50
13 December 1973	FA	30 Sec., Discon.	-149
13 December 1973	FB	30 Sec., Discon.	66
13 December 1973	FC	30 Sec., Discon.	-15
14 December 1973	FD	30 Sec., Discon.	-22
14 December 1973	FE	30 Sec., Discon.	11
14 December 1973	FF	30 Sec., Discon.	21
17 December 1973	FO	30 Sec., Discon.	-23
17 December 1973	FP	30 Sec., Discon.	-79
17 December 1973	FQ	30 Sec., Discon.	-10
17 December 1973	FR	30 Sec., Discon.	-49
17 December 1973	FS	30 Sec., Discon.	-7
17 December 1973	FT	30 Sec., Discon.	14
17 December 1973	FU	30 Sec., Discon.	-45
17 December 1973	FV	30 Sec., Discon.	-33
17 December 1973	FW	30 Sec., Discon.	38
17 December 1973	FX	30 Sec., Discon.	7
17 December 1973	FY	30 Sec., Discon.	29

Continued

Date	Test	Pump Status	Gauge Mass[a] (μgm)
17 December 1973	FZ	30 Sec., Discon.	4
17 December 1973	GA	30 Sec., Discon.	6
17 December 1973	GB	30 Sec., Discon.	-74
17 December 1973	GC	30 Sec., Discon.	106
17 December 1973	GD	30 Sec., Discon.	17
17 December 1973	GE	30 Sec., Discon.	-27
17 December 1973	GF	30 Sec., Discon.	-7
17 December 1973	GG	30 Sec., Discon.	-13
17 December 1973	GH	30 Sec., Discon.	-21
		Ave. Mass =	-4.9 μgm[a]
		σ =	53.8 μgm
11 December 1973	EN	30 Sec., Con.	51
11 December 1973	EO	30 Sec., Con.	67
11 December 1973	ER	30 Sec., Con.	61
14 December 1973	FG	30 Sec., Con.	150
14 December 1973	FH	30 Sec., Con.	112
14 December 1973	FI	30 Sec., Con.	115
14 December 1973	FJ	30 Sec., Con.	148
14 December 1973	FK	30 Sec., Con.	128
14 December 1973	FL	30 Sec., Con.	80
14 December 1973	FM	30 Sec., Con.	62
14 December 1973	FN	30 Sec., Con.	-4
17 December 1973	GI	30 Sec., Con.	158
17 December 1973	GJ	30 Sec., Con.	20
17 December 1973	GK	30 Sec., Con.	99
18 December 1973	GL	30 Sec., Con.	82
18 December 1973	GM	30 Sec., Con.	-16
18 December 1973	GN	30 Sec., Con.	-45
18 December 1973	GO	30 Sec., Con.	-73
18 December 1973	GP	30 Sec., Con.	51
18 December 1973	GQ	30 Sec., Con.	36
18 December 1973	GR	30 Sec., Con.	28
		Ave. Mass =	62.4 μgm[a]
		σ =	61.7 μgm

a) Gauge mass values shown are actual output values with initial IN calibration (for large scrim). Corrected values should reflect division by 2 (to convert to small scrim) and by 3 cm^2 (to convert to mass density).

Continued

Pump Disconnected

Ave. Mass = 2.4 μgm
σ = 26.9 μgm

Ave. Mass Density = 0.8 $\mu gm/cm^2$
σ = 9.0 $\mu gm/cm^2$

Pump Connected

Ave. Mass = 31.2 μgm
σ = 30.8 μgm

Ave. Mass Density = 10.8 $\mu gm/cm^2$
σ = 10.6 $\mu gm/cm^2$

DATA--THIRD TEST SERIES

Conditions

1. Fabricated gauge modified
   a. Accurate Locate Microswitch positioning
   b. Cassette diameter increased to 50.3 millimeters
   c. Scrim modified to prevent filter deflection
2. Single Cycle operation mode
3. Repeatability tests--no mass collected
4. 20 millimeter scrim
5. Nuclepore filter

Date	Test	Pump Status	Gauge Mass[a] (μgm)
11 December 1973	EA	30 Sec., Discon.	60
11 December 1973	EB	30 Sec., Discon.	-27
11 December 1973	EC	30 Sec., Discon.	-5
11 December 1973	ED	30 Sec., Discon.	-1
11 December 1973	EI	30 Sec., Discon.	30
11 December 1973	EK	30 Sec., Discon.	16
		Ave. Mass =	12.2 μgm[a]
		σ =	27.8 μgm
11 December 1973	EQ	30 Sec., Con.	28
11 December 1973	ES	30 Sec., Con.	43

a) Gauge mass values shown are actual output values with initial IN calibration (for large scrim). Corrected values should reflect division by 2 (to convert to small scrim) and by 3 cm^2 (to convert to mass density).

Pump Disconnected

Ave. Mass = 6.1 μgm
σ = 13.9 μgm

Ave. Mass Density = 2.0 μgm/cm^2
σ = 9.1 μgm/cm^2

DATA--THIRD TEST SERIES

Conditions

1. Fabricated gauge modified
   a. Accurate Locate Microswitch positioning
   b. Cassette diameter increased to 50.3 millimeters
   c. Scrim modified to prevent filter deflection
2. Single cycle operation mode
3. Repeatability tests--no mass collected
4. 20 millimeter scrim
5. Pallflex filter

Date	Test	Pump Status	Gauge Mass[a] (μgm)
11 December 1973	EH	30 Sec., Discon.	-3
11 December 1973	EL	30 Sec., Discon.	-44
19 December 1973	GS	30 Sec., Discon.	20
19 December 1973	GT	30 Sec., Discon.	32
19 December 1973	GU	30 Sec., Discon.	30
		Ave. Mass =	-7.0 μgm[a]
		σ =	28.4 μgm
11 December 1973	EP	30 Sec., Con.	43
11 December 1973	ET	30 Sec., Con.	-46
19 December 1973	GV	30 Sec., Con.	43
19 December 1973	GW	30 Sec., Con.	30
19 December 1973	GX	30 Sec., Con.	56
		Ave. Mass =	25.2 μgm[a]
		σ =	40.5 μgm

a) Gauge mass values shown are actual output values with initial IN calibration (for large scrim). Corrected values should reflect division by 2 (to convert to small scrim) and by 3 cm^2 (to convert to mass density).

Pump Disconnected

Ave. Mass = 3.5 μgm
σ = 14.2 μgm

Continued

Ave. Mass Density = 1.2 μgm/cm^2
σ = 4.7 μgm/cm^2

Pump Connected

Ave. Mass = 12.6 μgm
σ = 20.4 μgm

Ave. Mass Density = 4.3 μgm/cm^2
σ = 6.8 μgm/cm^2

DATA--THIRD TEST SERIES

Conditions

1. Fabricated gauge modified
   a. Accurate Locate Microswitch positioning
   b. Cassette diameter increased to 50.3 millimeters
   c. Scrim modified to prevent filter deflection
2. Single Cycle operation mode
3. Repeatability tests--no mass collected
4. 20 millimeter scrim
5. H95E filter

Date	Test	Pump Status	Gauge Mass[a] (μgm)
16 January 1974	GY	30 Sec., Discon.	-55
16 January 1974	GZ	30 Sec., Discon.	19
16 January 1974	HA	30 Sec., Discon.	1
		Ave. Mass =	-11.7 μgm[a]
		σ =	31.5 μgm
16 January 1974	HB	30 Sec., Con.	54
16 January 1974	HC	30 Sec., Con.	59
16 January 1974	HD	30 Sec., Con.	-13
		Ave. Mass =	33.3 μgm[a]
		σ =	32.8 μgm

a) Gauge mass values shown are actual output values with initial IN calibration (for large scrim). Corrected values should reflect division by 2 (to convert to small scrim) and by 3 cm^2 (to convert to mass density).

Pump Disconnected

Ave. Mass = 5.8 μgm
σ = 15.7 μgm

Ave. Mass Density = 1.9 μgm/cm^2
σ = 5.3 μgm/cm^2

Pump Connected

Ave. Mass = 16.6 μgm
σ = 16.4 μgm

Ave. Mass Density = 5.6 μgm/cm^2
σ = 5.5 μgm/cm^2

DATA--FOURTH TEST SERIES

Conditions

1. Gauge fully modified and improved
2. Single Cycle operation mode
3. Calibration with tobacco smoke at IN
4. 20 millimeter scrim
5. Pallflex filter

Date	Test	Gauge Mass[a] (µgm)	Balance Mass (µgm)	Δ (µgm)
21 January 1974	HE	8,031	9,200	-1,169[b]
21 January 1974	HF	3,605	3,400	205
21 January 1974	HG	1,881	1,700	181
21 January 1974	HH	234	300	-66
21 January 1974	HI	3,682	3,800	-128
21 January 1974	HJ	2,894	2,700	194
21 January 1974	HK	3,106	3,300	-194
21 January 1974	HL	7,057	7,300	-243[b]
21 January 1974	HM	5,553	5,800	-247
22 January 1974	HN	1,012	1,000	12
22 January 1974	HO	1,825	1,900	-75[b]
22 January 1974	HP	6,792	7,300	-508[b]
23 January 1974	ID[c]	2,456	2,200	256
23 January 1974	IE[c]	10,190	11,600	-1,410[b]
23 January 1974	IF[c]	6,012	6,300	188

σ = 183 µgm[a]
or 61 µgm/cm^2

a) All gauge mass values are computed from actual output values divided by 2.00, the correction constant for converting from the initial IN calibration (for large scrim) to the proper calibration for tobacco smoke/Pallflex filters, small scrim.
b) Excluded from calibration calculations (out of specification range or technical measurement error noticed).
c) Measured in Federal Cycle

DATA--FOURTH TEST SERIES

Conditions

1. Gauge fully modified and improved
2. Single Cycle operation mode
3. Calibration with tobacco smoke at IN
4. 20 millimeter scrim
6. Gelman Type A filter

Date	Test	Gauge Mass[a] (μgm)	Balance Mass (μgm)	Δ (μgm)
22 January 1974	HQ	5,832	6,100	-268
22 January 1974	HR	2,836	2,800	36
22 January 1974	HS	3,047	3,100	-53
22 January 1974	HT	4,369	4,200	169
22 January 1974	HU	969	900	69

σ = 148 μgm[a]
or 49 μgm/cm^2

a) All gauge mass values are computed from actual output values divided by 2.62, the correction constant for converting from the initial IN calibration (for large scrim) to the proper calibration for tobacco smoke/Gelman Type A filters, small scrim.

DATA--FOURTH TEST SERIES

Conditions

1. Gauge fully modified and improved
2. Single Cycle operation mode
3. Calibration with tobacco smoke at IN
4. 20 millimeter scrim
5. H95E filter

Date	Test	Gauge Mass[a] (μgm)	Balance Mass (μgm)	Δ (μgm)
22 January 1974	HV	6,564	7,200	-636[b]
22 January 1974	HW	4,520	4,300	220
22 January 1974	HX	3,577	3,700	-123
22 January 1974	HY	883	1,000	-127
22 January 1974	HZ	1,699	1,400	299
22 January 1974	IA	2,228	2,000	228
22 January 1974	IB	4,179	4,400	-221
22 January 1974	IC	3,289	3,300	-11

σ = 196 μgm[a]
or 65 μgm/cm^2

a) All gauge mass values are computed from actual output values divided by 2.56, the correction constant for converting from the initial IN calibration (for large scrim) to the proper calibration for tobacco smoke/H95E filters, small scrim.
b) Excluded from calibration calculations (out of specification range).

DATA--FOURTH TEST SERIES

Conditions

1. Gauge fully modified and improved
2. Federal Cycle operation mode (21/210/21 second pump time)
3. Calibration with tobacco smoke at IN
4. 20 millimeter scrim
5. H95E filter

Date	Test	Gauge Mass (μgm)	Balance Mass (μgm)	Δ (μgm)
23 January 1974	IG	4,311[a]	4,300	11
23 January 1974	IH	842[a]	800	42
23 January 1974	IJ	5,517[a]	6,300	-783[b]
23 January 1974	IK	3,272[a]	3,300	38
23 January 1974	IL	1,215[c]	1,000	215
23 January 1974	IM	8,210[c]	9,200	-990[b]
23 January 1974	IN	3,303[c]	3,200	103
23 January 1974	IO	2,151[c]	2,000	-49
23 January 1974	IP	7,546[c]	9,300	-1,754[b]
23 January 1974	IQ	4,934[c]	4,800	134

σ = 107 μgm[a,c]
or 36 μgm/cm²

a) Gauge mass values are computed from actual output values divided by 2.56, the correction constant for converting from the initial IN calibration (for large scrim) to the proper calibration for tobacco smoke/H95E filters, small scrim.
b) Excluded from calibration calculations (out of specification range)
c) Actual output values with final IN calibration

DATA--FIFTH TEST SERIES

Conditions

1. Gauge fully modified and improved
2. Single Cycle operation mode
3. Tests with fluorescein aerosol at EPA
4. 20 millimeter scrim--no filter guard ring
5. H95E filters

Date	Test	Gauge Mass[a] (μgm)	Balance Mass (μgm)	Δ (μgm)
29 January 1974	IR	550	552	-2
29 January 1974	IS	429	426	3
29 January 1974	IT	841	727	117
29 January 1974	IU	404	294	110
29 January 1974	IV	1,045	942	103
29 January 1974	IW	358	547	-189

σ = 110 μgm[a]
or 37 μgm/cm^2

a) All gauge mass values are computed from actual output values divided by 1.38, the correction constant for converting from the final IN calibration (tobacco smoke/H95E filter, small scrim).

DATA--FIFTH TEST SERIES

Conditions

1. Gauge fully modified and improved
2. Single Cycle operation mode
3. Tests with fluorescein aerosol at EPA
4. 20 millimeter scrim with filter guard ring
5. H95E filter

Date	Test	Gauge Mass (µgm)	Balance Mass (µgm)	Δ (µgm)
29 January 1974	IX	1,298[a]	1,146	152[b]
29 January 1974	IY	446[a]	363	83[b]
30 January 1974	IZ	353[a]	391	-38
30 January 1974	JA	1,081[a]	1,054	27
30 January 1974	JB	1,545[a]	1,472	73
30 January 1974	JC	523[a]	571	-48
30 January 1974	JD	114[a]	111	3
30 January 1974	JE	1,467[a]	1,362	105[b]
30 January 1974	JF	357[a]	354	3
30 January 1974	JG	464[c]	383	79
30 January 1974	JH	469[c]	439	30
30 January 1974	JI	452[c]	429	23

σ = 44 µgm[a,c]
or 15 µgm/cm^2

a) Gauge mass values are computed from actual output values divided by 1.62, the correction constant for converting from the final IN calibration (tobacco smoke/H95E filter, small scrim).
b) Excluded from calibration calculations (filter guard ring faulty).
c) Actual output values with 30 January 1974 calibration modification.

OPERATION MANUAL

for

ADVANCED PROTOTYPE DIRECT READING INSTRUMENT FOR PARTICULATE MASS MEASUREMENT

December, 1973

Contract No. 68-02-0782

Environmental Protection Agency

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Computer Program

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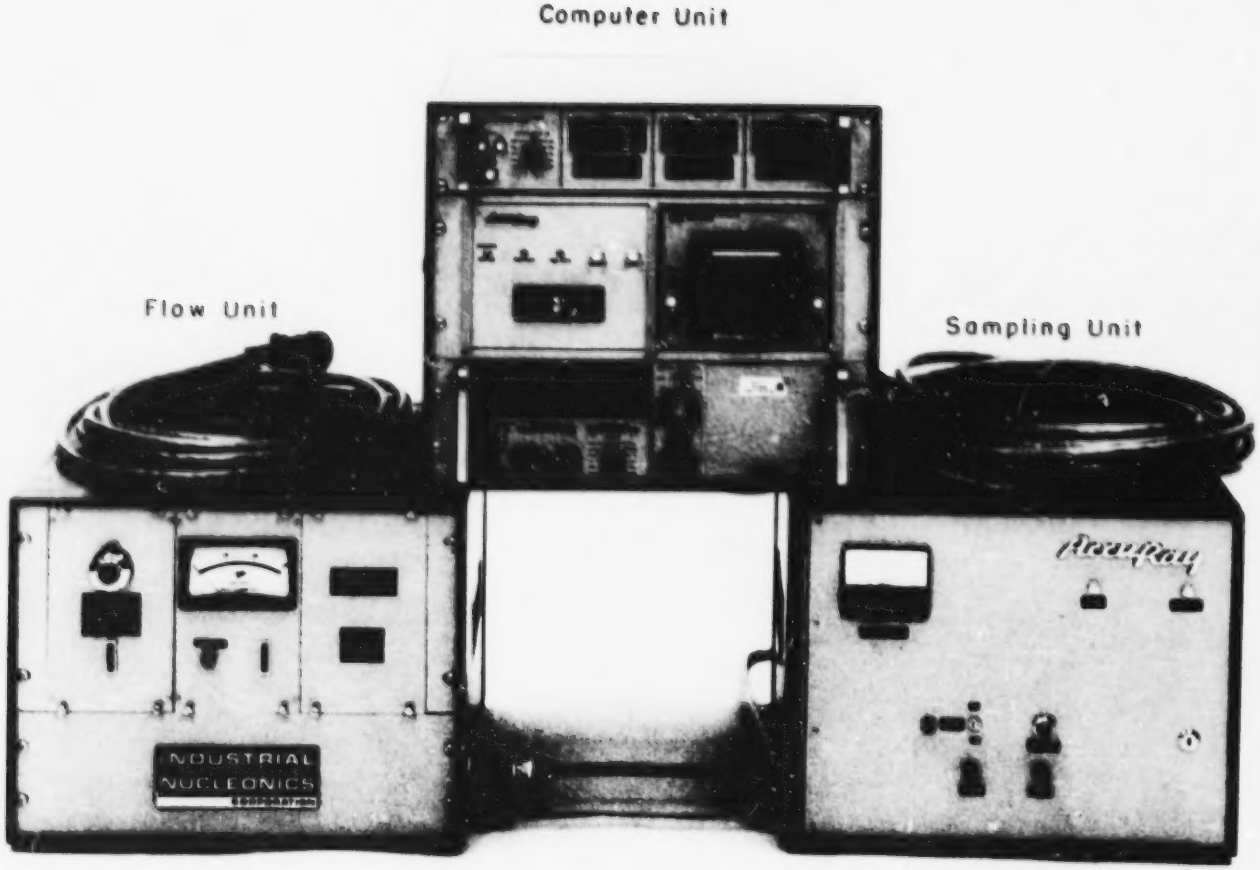
1.0 INTRODUCTION

The Particulate Emission Gauge is a very sophisticated instrument with a wide range of flexibility. The gauge, shown in Figure 1, is composed of three major sub-modules which enhance the operation, flexibility, and maintainability of the gauge. The sub-modules are (a) the Computer Unit, (b) the Sampling Unit, and (c) the Flow Unit. Due to the wide flexibility available, some experience with the instrument is required in order to achieve optimum results. It is therefore recommended that this manual be read completely and thoroughly prior to any attempt at operation.

The intended use of the instrument is for measurement of particles from mobile sources. Additional possible applications include stationary source and ambient air monitoring as well as particulate measurement in any other gaseous media. Some preparation of the mobile source sample is usually required to reduce the relative humidity of the exhaust, which normally contains water in a supersaturated state.

Below are discussed several major operating parameters governing the use of this instrument. Others will become evident as the manual is read.



VEHICLE EXHAUST PARTICULATE EMISSION GAUGE

Figure 1

1.1 Sensitivity and Range

The lower sensitivity limit of this unit is expressed in terms of a resolution of areal density. This limit is 30 ± 10 micrograms per square centimeter ($\mu g/cm^2$), so that for a three square centimeter effective collection area, the minimum total mass resolution is 90 ± 30 micrograms. Obviously, then, if a result is desired accurate to 10% or less, at least 300 micrograms must be collected. Correspondingly, for a six square centimeter effective collection area, at least 600 micrograms must be collected to achieve the same accuracy.

This unit has been designed to use virtually all types of filter media. As a practical upper limit of measurement, or range, one should utilize filters for specific applications such that the combined areal density of filter and particles does not exceed 10 milligrams per square centimeter (mg/cm^2). In addition, the maximum particulate detection limit is 2 mg/cm^2. Thus, for a medium with an initial areal density of 5 mg/cm^2 and an effective collection area of 3 cm^2, only 6 mg total should be collected; with an initial areal density of 9 mg/cm^2 for the filter and the same collection area, only 3 mg total should be collected.

Utilizing these numbers and considering the application, certain operating parameters can be determined in advance. Assuming an ambient concentration of 100 $\mu g/m^3$, collecting 300 μg will require processing 3 m^3. This can be achieved through a combination of flow rate and collection time; e.g., 100 ℓ/min

for 30 minutes, 50 ℓ/min for 60 minutes, and so forth. On the other hand, for a very dirty environment of, say, 10 mg/m^3, one should not process more than 0.6 m^3 (for a filter areal density of 8 mg/cm^2 or less).

The flow rates achievable with this unit as well as other important application considerations are discussed in later sections of this manual.

1.2 Flow Adjustment

The flow rate is controlled automatically by the Hastings flow control units. This flow is continuously adjustable and can be set at 40, 80, or 100 ℓ/min (depending on the type and characteristics of the filter medium employed). Obviously, for low concentrations high flow rates should be used, and vice versa. The adjustment of the flow rate is available on the front of the Flow Unit. By placing the SET FLOW switch in the "ON" position, the flow can be adjusted by turning the SET POINT potentiometer. When the new desired flow is obtained, the SET POINT potentiometer should be locked in position and the SET FLOW switch turned to "OFF." (This does not actually draw air through the filter but merely draws air through an orifice located in the Sampling Unit to simulate a filter. Thus, the flow set point can be preset and cause a minimum of disturbance to the flow control system when an actual test is initiated.)

1.3 Beta Collection and Sample Collection Adjustment Range

Both these times are integrally tied to the MEASUREMENT TIME and MULTIPLIER settings on the Hewlett-Packard Computing Counter and the thumbwheel switch settings on the Systems Programmer. Ordinarily, MEASUREMENT TIME is set on "1 s" and MULTIPLIER is on "1." When this is the case, the thumbwheel settings (for COLLECTION TIME I and II) are in seconds. This gives a minimum increment of time of 1 second and a maximum of any desirable number of seconds up to 10^9. The beta collection is fixed at 200 increments and thus is typically 200 seconds.

1.4 Temperature Requirements

The unit has been designed to operate in ambient room temperature. Therefore, a practical limit of operation is +50 degrees Fahrenheit to +100 degrees Fahrenheit. At higher temperatures, it is advisable to take extra steps to keep the equipment cool.

1.5 Power Consumption

The circuit-breaking requirements are 115 volt, 60 cycle, 20 amperes and are implemented in the form of one 10-ampere breaker in the Computer Unit and one in the Flow Unit. The Sampling Unit also has a 10-ampere breaker for use in removing power from this unit; however, it is powered through the breaker in the Computer Unit so that the interconnect cable is protected.

In the event any of these breakers are tripped, it is necessary to reset the breakers prior to operating (after first determining and correcting the cause of the trippage).

1.6 Inlet Heater

A heater and a temperature indicator are incorporated to allow the operator to select any desired inlet temperature above ambient up to 200 degrees Fahrenheit. The purpose of this is to reduce the amount of moisture condensation on the inlet pipe. The temperature is adjusted by changing the TEMP ADJUST potentiometer on the front of the Sampling Unit to the desired new temperature and locking it in position.

2.0 TECHNICAL DISCUSSION

The particulate measurement system is capable of monitoring the emissions from mobile sources in a variety of modes. Specifically, the system is capable of monitoring emissions for the Federal Cycle test (described in the Federal Register, Part II, Vol. 37, Number 221, November 15, 1972) on automobiles, and printing the particulate mass collected in the three phases of that cycle. Other modes of operation are also provided, so that the instrument is capable of a variety of mobile and stationary source monitoring functions.

2.1 System Concept

The basic measurement of particulate emissions is accomplished through careful determination of the attenuation of beta radiation by the matter collected on a filter. The passage of beta radiation through sheet materials obeys an exponential law:

$$I = I_o e^{-\mu \rho x}$$

where I = transmitted radiation intensity

I_o = incident radiation intensity

μ = mass attenuation coefficient

ρ = density of sheet material

x = thickness of sheet material.

By solving this equation, one can obtain the mass per unit area (ρx) as follows:

$$\rho x = \frac{1}{\mu} \ln(I_o/I).$$

This transmission measurement technique of beta radiation has been the most successful method of mass measurements. Therefore, the particulate concentration in air or other forms of gas can be determined accurately by measuring the mass of a filter before and after the collection of particles. The success of the beta measurement technique is based on the fact that the mass absorption coefficient of beta particles is nearly independent of the atomic weight of the absorbing media, rising only slightly with increasing atomic number (see, for example, The Atomic Nucleus by R. D. Evans, McGraw Hill, New York, 1955, p. 627). This, in turn, is based on the fact that the dominating energy loss mechanism of beta particles is inelastic scattering by orbital electrons. Thus, the atomic energy absorption cross section is proportional to the number of orbital electrons or the atomic number. Since the mass of individual atoms is also nearly proportional to the atomic number except for hydrogen, the "mass" absorption coefficient is nearly independent of the atomic composition of the measured medium. Even though hydrogen is an exception to this general statement, the mass fraction of hydrogen of most samples is rather small. If the calibration curve for the measurement is

determined experimentally, only the fluctuation of hydrogen mass from the calibration samples is of concern and generally this can be neglected. Interaction of beta particles with atomic nuclei involves only a small probability of energy loss but can result in a significant scattering of the radiation. Therefore, the instrument has been designed to minimize the effect of nuclear scattering.

2.2 System Description

Three major subsystems, packaged separately, are utilized to provide the measurement. These are (a) the Flow Unit, (b) the Sampling Unit, and (c) the Computer Unit.

Composed of a pump, mass flowmeter, and a flow controller, the Flow Unit provides constant, preselectable flow throughout an individual measurement. Flows of 40, 80, or 100 liters/minute are available but are dependent on the filter medium employed (see Section 3.5).

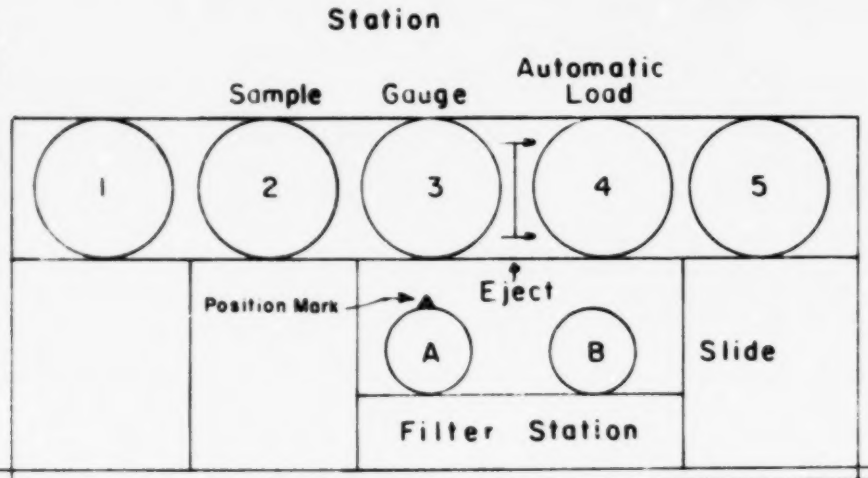
The Sampling Unit includes a filter cassette transfer mechanism, a Carbon-14 beta radiation source, a scintillator/photomultiplier detector, and a sampling station. Precise location of a slide containing one or two cassettes is produced by a rack and gear drive.

Data processing and logic sequencing of functions within the gauge are provided by the Computer Unit. These

electronics are located in the Computing Counter (HP 5360A), the Systems Programmer (HP 5376A), and the Computer Interfacing Board. This electronic system provides extremely accurate counting and calculating capability and precise system logic control through a small, hard-wired program.

Since the weight per unit area of a given filter medium can vary to a significant degree from filter to filter (variations can be comparable to the particulate deposition), two attenuation measurements must be made for each filter: an initial count prior to collection of the particulate sample (standardization), and a final count after collection of the sample (measurement). The particulate mass can be determined from the difference in attenuation inferred from the two measurements.

In order to implement both Single and Federal Cycle operations, the Systems Programmer provides appropriate logic sequencing for various instrument functions. A diagram of instrument operation is indicated in Figure 2. The cassette slide mechanism (CSM) accurately moves to four positions through the action of a rack and gear drive. The CSM can hold two filter cassettes and move these cassettes into any pair of adjacent table stations. When the CSM moves from the



Carrier Slide Position	Function
	Single Cycle Mode
1 → 2 → 3 → 2 → 3	1. Load B_1 2. Standardize B_1 3. Sample * 4. Measure B_1 5. Eject B_1 & Load B_1' Repeat steps 2–5.
	Federal Cycle Mode
1 → 2 → 3 → 4 → 3 → 2 → 3 → 2 → 1 → 2 → 3 → 4	1. Load B_1 2. Load A 3. Standardize A 4. Standardize B_1 5. Sample B_1 (505 sec.) * 6. Measure B_1 & Sample A (866 sec.) 7. Eject B_1, Load B_2, Measure A 8. Standardize B_2 9. Sample B_2 (505 sec.) * 10. Measure B_2 11. Eject B_2, Load B_1' 12. Eject A, Load A' Repeat steps 2–11.

* Generally, Sample collection on a B filter is initiated manually, however, in Automatic Single Cycle such collection is automatic.

INSTRUMENT OPERATIONS

Figure 2

gauge station (3) to the automatic load station (4), the cassette is ejected, while motion of the CSM across the ejector in the opposite direction does not cause ejection. Details of the functional sequences are described in the following sections.

2.2.1 Single Cycle Mode

The instrument is capable of operating for extended periods of time in a Single Cycle mode. Essentially, filter cassettes are loaded in the automatic load magazine (station 4), sampling lines are connected, the desired sampling time is dialed into the programmer (COLLECTION TIME I thumbwheel), and sample collection and measurement cycles are repeated (if automatic operation is selected) until the instrument is turned off.

Single Cycle operation is depicted in Figure 2. A detailed description of the Single Cycle follows:

Step	Slide Position	Functions
1	3	Load B_1. Initiation of the instrumentation program drives the CSM to position 3, thus loading a filter.
2	2	Standardize B_1. The CSM moves to position 2 with cassette B_1 at the gauge station. The standardization count (N_{BS}) is printed.
3	1	Sample. The CSM moves to position 1 with cassette B_1 at the sample station. Any cassettes in A position may be removed since the A filter

Step	Slide Position	Functions
		station is not used in Single Cycle. In automatic mode, the cassette is clamped in the sample station and the pump is actuated. In manual mode, clamping and pumping are initiated manually. The flow volume count (N_F) is printed.
4	2	Measure B_1. The CSM moves to position 2 with cassette B_1 at the gauge station. The measurement count (N_{BM}), mass collected (Y), volume collected (V), mass/volume (Y/V), and collection time (T) are printed.
5	3	Eject B_1 and Load B_2. The slide moves to position 3. As it does so, cassette B_1 is ejected. In position 3, a new cassette (B_2) is loaded from the magazine.

Repeat steps 2-5.

A typical printout for the Single Cycle is as follows:

```
+03+18000
+02+29890
-00+10887
+02+32541
+06+13193
+07+21774
+06+13686
```

Interpretation:

Standardization: 1.3686×10^6 counts

Flow: 2.1774×10^7 counts

Measurement:	1.3195×10^{0} counts
Collected Mass:	3.2541×10^{2} micrograms
Volume:	1.0887×10^{0} cubic meters
Concentration:	2.9890×10^{2} $\mu g/m^3$
Collection Time:	1.8000×10^{3} seconds

2.2.2 Federal Cycle Mode

The Federal Cycle requires three separate samples, the first two samples being taken immediately after one another. The cycle requires 505-second and 900-second samples to be taken in sequence. Then, after a pause of 10 minutes, a third sample, also of 505 seconds, is taken.

Federal Cycle instrument operation is also indicated in Figure 1. A detailed description of the cycle follows:

Step	Slide Position	Functions
1	5	Load B_1. Initiation of the instrument program drives the CSM to position 5, thus loading filter B_1.
2	4	Load A. The instrument program drives the CSM to position 4, thus loading filter A.
3	3	Standardize A. The CSM moves to position 3 with cassette A at the gauge station. The program standardizes A for 200 seconds. The standardization count (N_{AS}) is printed.
4	2	Standardize B_1. The CSM moves to position 2 with cassette A at the sample station and B_1 at the gauge station. The standardization count (N_{B1S}) is printed.

Step	Slide Position	Functions
5	1	Sample B_1. The CSM moves to position 1 and operations hold until clamping and pumping on cassette B_1 in the sample station are initiated by an operator (when in the Manual Mode). This action normally corresponds to the start of the Federal Cycle with the emission source. The air standardization count for 535 seconds (N_{A1}) is printed (but is not used).
6	2	Measure B_1 and sample A. The CSM moves to position 2 and A is automatically clamped in the sample station. While a sample is being collected on A (860 seconds), cassette B_1 is measured in the gauge station for 200 seconds. The B_1 measurement count (N_{B1M}) and the mass collected (M_1) are printed. Additionally, a second measurement count on B_1 (N_{B1M}) taken for the remaining 660 seconds is printed (but not used).
7	3	Eject B_1, load B_2, Measure A. The CSM moves to position 3, thus causing the ejection of cassette B_1 and the loading of a new cassette, B_2. Cassette A is measured in the gauge station. The A measurement count (N_{AM}) and the mass collected (M_2) are printed.
8	2	Standardize B_2. The CSM moves to position 2 with cassette B_2 at the gauge station. The standardization count (N_{B2S}) is printed.
9	1	Sample B_2. The CSM moves to position 1 and operations hold until clamping and pumping on cassette B_2 in the sample sta-

Step	Slide Position	Function
		tion are initiated by an operator. This action normally occurs 10 minutes after the conclusion of sample collection on cassette A. The air standardization count for 505 seconds (N_{air}) is printed (but not used).
10	2	Measure B_2. The CSM moves to position 2 with cassette B_2 in the gauge station. The B_2 measurement count (N_{B_2M}), the mass collected (Y_3), the average emissions (Y), and the sample flow constant ($C = x/qm$) are printed.
11	3	Eject B_2, Load B_1'. The CSM moves to position 3, thus causing the ejection of cassette B_2 and the loading of a new cassette B_1'.
12	4	Eject A, Load A'. The CSM moves to position 4, thus causing the ejection of cassette A and the loading of a new cassette A'.

Repeat steps 3-12

A typical printout for the Federal Cycle is as follows:

```
+02+50000
-01+37066
+02+44964
+06+13231
+07+25197
+06+13919
+01+93781
+06+13642
+06+44692
+02+55401
+06+13421
+07+25193
+06+14286
+06+13787
```

Interpretation:

A Standardization:	1.3787×10^{6} counts
B_1 Standardization:	1.4276×10^{6} counts
Air Standardization: (made for 505 seconds, not used)	2.5193×10^{5} counts
B_1 Measurement:	1.3431×10^{6} counts
Y_1:	3.5402×10^{5} micrograms
B_1 Measurement #2: (made for 866 seconds, not used)	1.4698×10^{6} counts
A Measurement:	1.3642×10^{6} counts
Y_2:	3.7781×10^{5} micrograms
B_2 Standardization:	1.3916×10^{6} counts
Air Standardization: (made for 505 seconds, not used)	2.5107×10^{5} counts
B_2 Measurement:	1.3251×10^{6} counts
Y_3:	4.1964×10^{5} micrograms
$Y = \frac{X}{QM}(aY_1 + bY_2 + Y_3)$:	3.7066×10^{-1} grams/mile
$\frac{X}{QM}$:	5.0000×10^{2} per mile

2.3 Measurement Precision

In the measurement of particulate mass per unit area of filters using a beta source, various errors occur due to count loss, change in air-gap conditions, change in sample conditions, change in the sample composition, moisture content, etc., in addition to the error associated with the statistical nature of nucleonic measurements.

Through good system design the effective path-length (areal density) of beta particles through air can be as little

as 1 cm (about 1.2 mg/cm^2). If the absolute temperature of the gap is maintained to within 1% (about 5°F) between stabilization of a filter and measurement of that same filter, temperature effects produce ± 0.5% or ± 6 μg fluctuations about a mean value of 1.2 mg/cm^2. A filter mass normalization measurement is made prior to collection of the sample to eliminate the potential error due to nonuniformity between filter discs. However, since the filter is subjected to a reasonably high differential pressure during the sampling, the disc may deform somewhat and thereby change its mass per unit area. A mesh backing minimizes this effect. However, if an effective filter mass change of 0.1% of an original value of 3 mg/cm^2 occurs, an error of ± 0.1% or ± 3 μg/cm^2 may occur. From the above considerations, it appears that the nonstatistical measurement error does not exceed 10 μg/cm^2. The required measurement accuracy is 30 ± 10 μg/cm^2 so that these nonstatistical effects appear compatible with the requirement.

2.4 Detector

Detector selection is largely determined by count rate requirements. The range of count rates from 3.5×10^3 to 30×10^3 counts per seconds excludes GM tubes (with a maximum count rate of about 2.5×10^3 counts/second) from consideration. While solid state detectors might be used, scintillator/photomultiplier tube detectors exhibit somewhat superior noise, ruggedness, and cost characteristics. A CaF_2 scintillator

covered with a thin window (0.9 mg/cm^2) appears most satisfactory for this application. The combination was previously employed in the prototype particulate measurement instrument and exhibited satisfactory performance there also.

2.5 Mechanical Assembly

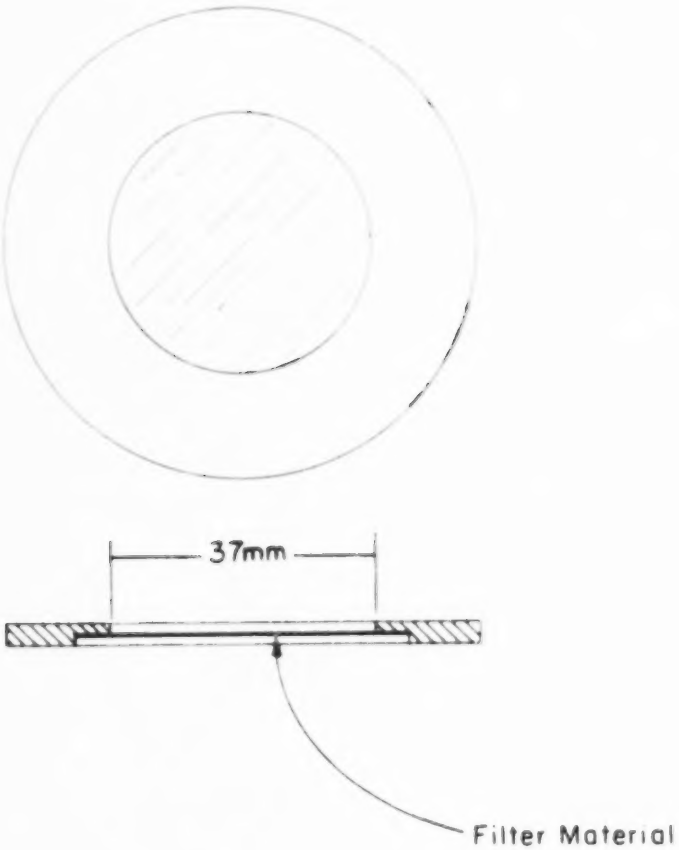
2.5.1 Filter Cassette Design

The filter material is mounted in a recess on the top of a cassette (Figure 5) for protection and ease of handling. The cassette can be made of a variety of materials either through machining or injection molding. The recess protects the filter material from abrasion against an adjacent surface, and the hole through the center provides for the radiation path and allows the gas to flow through the filter.

A maximum of 12 cassettes can be loaded into a magazine from which they are taken automatically one at a time. After going through the cycle, they are ejected and may be prepared for re-use by stripping off the used filter and applying a new one. In quantities, it is recommended that the cassettes be injection molded, so as to make the cassettes inexpensive enough to justify expendable use.

2.5.2 Cassette Transfer Mechanism

The cassette transfer mechanism is a lightweight aluminum carrier slide of slightly greater thickness than the cassette and has two pockets each of which holds a cassette. The carrier slide can be positioned successively at four different locations. This is achieved by means of



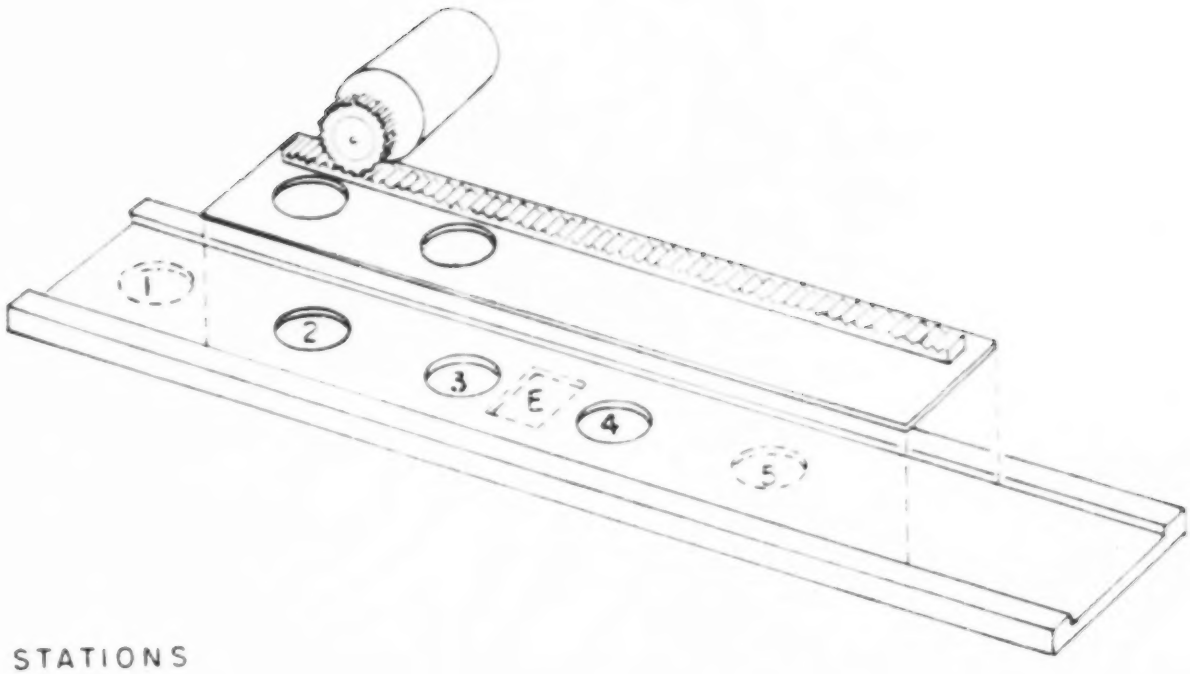
FILTER CASSETTE

Figure 3

a motor-driven gear rack mounted to the transfer slide (Figure 4). Repeatable location of the cassette is of utmost importance and is achieved by braking the motor when the desired position is achieved.

In each complete cycle (refer to Section 2.5, Figure 2 for the particular succession of events outlined for each cycle; for simplicity only the single case is discussed here), a cassette is loaded from the magazine toward the action of a constant force spring. The cassette is then moved to the gauging station where the beta attenuation of the clean filter is measured. The cassette is then transferred to the collection station where two O-ring seals are pressed by a solenoid against the upper and lower surfaces of the cassette to exclude the surrounding air, and the gas to be measured is drawn through the filter by the vacuum pump. After the required amount of gas has been filtered, the cassette is transferred back to the gauging station where the amount of the material collected on the filter is determined. On the next motion of the carrier slide, the used cassette is stripped out of the slide by two spring fingers and dumped through a hole in the base. When the slide pocket reaches the loading station, it is ready to accept a new cassette from the magazine.

The wait station (see Figure 4) serves a dual purpose in that it is utilized for a wait period during the Federal Cycle and provides a means to insert standard samples for calibration



STATIONS

5 HOLD
4 LOAD
E PASSIVE REJECT
3 MEASURE
2 COLLECTION
1 WAIT

Figure 4

CARRIAGE SLIDE ASSEMBLY

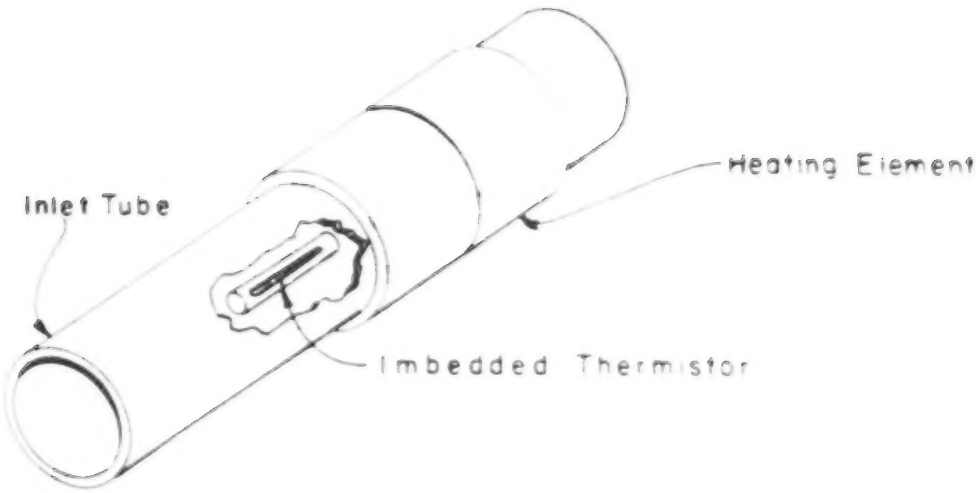
of the instrument. A superior method for calibration is described in Section 3.7.

2.3.3 Gas Flow System

The gas to be measured is brought in directly to the filter through a stainless steel tube that has a 1.12 inch inner diameter and a 1.25 inch outer diameter. To prevent the particles from condensing on the inner walls of the tube, the inlet probe (located in the sample collection unit) is independently thermostatically controlled over a range of temperatures from ambient to 200 ± 2°F. Control of the temperature is achieved by using a thermistor sensor attached to the wall of the inlet probe. The inlet probe is surrounded by a heating element to maintain the desired inlet temperature (see Figure 2-).

The flow rate is monitored downstream of the filter by means of a thermal-type mass flowmeter manufactured by Hastings-Raydist. This unit has an accuracy of ± 1% of range for a 20% variation in pressure and temperature, and ± 2% over the entire pressure and temperature ratings, with a linearity and repeatability of ± 1/2% of range. The flowmeter is connected through a controller to a motor-operated by-pass valve which regulates the amount of ambient air that is allowed to enter the gas flow upstream of the vacuum pump. After passing through the vacuum pump, the gas and air are vented to the atmosphere.

As material accumulates on the filter, it is necessary to increase the pressure drop across the filter so as to maintain



THERMOSTATICALLY CONTROLLED INLET PROBE

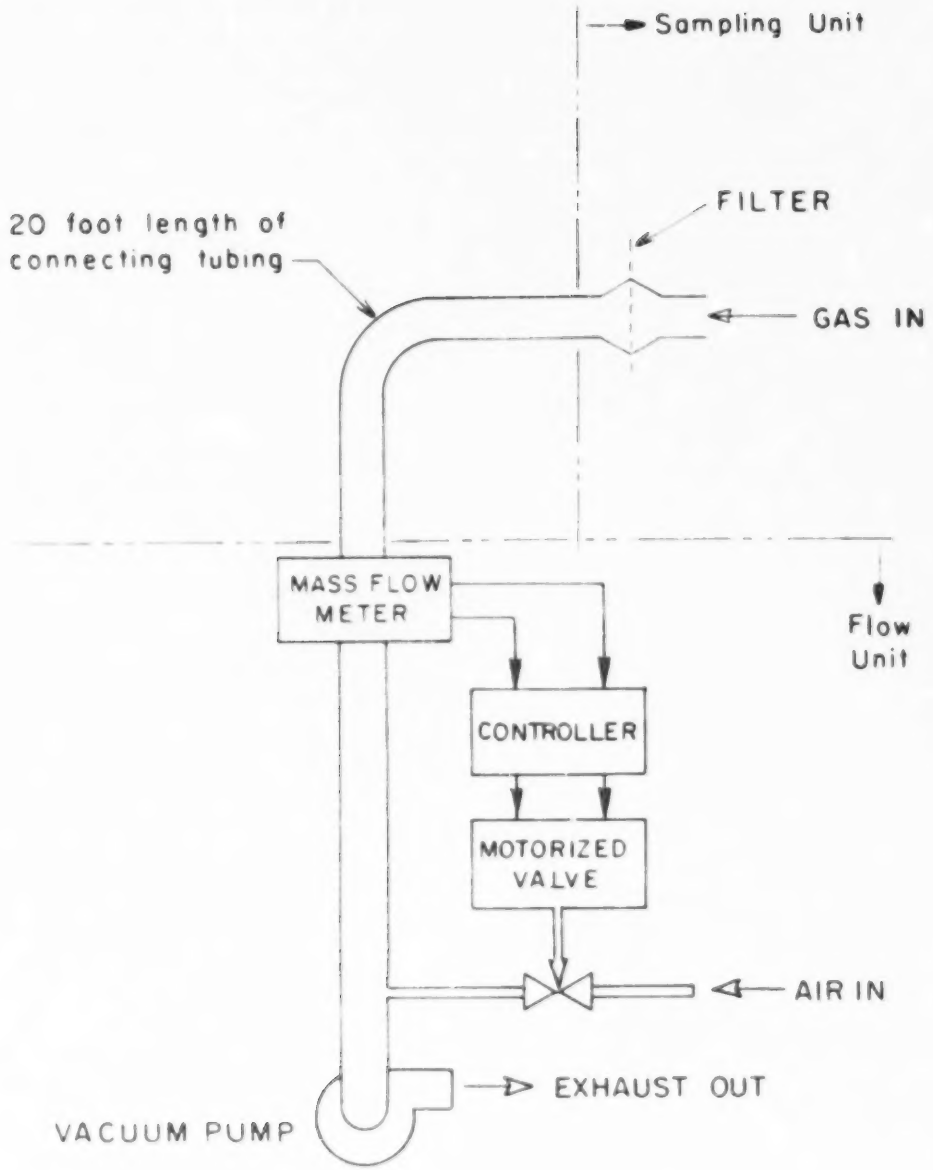
Figure 5

a constant flow. In order to achieve the increased pressure drop and thereby a constant flow, the by-pass valve is inserted via a tee connection on the downstream side of the filter (Figure 6). Partially closing the by-pass valve causes the pump to pull a greater vacuum on the filter. The pressure drop across the pump then will never be greater than the pressure drop across the filter. Thus, the pump will be running with a light load and wear will be reduced.

Various flow rates through the filter may be selected by a dial, including 40 liters/minute, 80 liters/minute, and 100 liters/minute. During collection, flow through the filter will be automatically maintained constant within ± 5% of the initial rate by the mass flowmeter (assuming the composition of the exhaust gas does not vary excessively from the gas composition to which the flowmeter is calibrated).

A large variation in the composition of the gas during a run could result in a variation in the flow rate (Table I). For instance, if the flowmeter were calibrated with a gas composed of 85% air, CO and NO, and 15% CO_2, the calibration factor would be:

air, CO and NO	0.85 x 1.00 =	0.85
CO_2	0.15 x 0.73 =	0.11
		0.96



FLOW DIAGRAM

Figure 6

GAS CONVERSION FACTORS FOR HASTINGS LINEAR MASS FLOWMETERS					
NAME OF GAS	SYMBOL	HASTINGS CONVERSION FACTOR +	NAME OF GAS	SYMBOL	HASTINGS CONVERSION FACTOR +
ACETYLENE	C_2H_2	.67	HELIUM	He	*1.43
AIR		*1.00	HYDROGEN	H_2	*1.03
AMMONIA	NH_3	.77	HYDROGEN CHLORIDE	HCl	1.01
ARGON	A	*1.43	HYDROGEN FLUORIDE	HF	1.00
ARSINE	AsH_3	.76	HYDROGEN SULFIDE	H_2S	.80
BROMINE	Br_2	.88	ISOBUTANE	C_4H_{10}	.33
BUTANE	C_4H_{10}	.30	KRYPTON	Kr	1.39
BUTENE 1	C_4H_8	.34	METHANE	CH_4	*.69
CARBON DIOXIDE	CO_2	*.73	NEON	Ne	1.38
CARBON MONOXIDE	CO	*1.00	NITRIC OXIDE	NO	1.00
CHLORINE	Cl_2	.85	NITROGEN	N_2	*1.02
CHLORINE TRIFLUORIDE	ClF_3	.99	NITROUS OXIDE	N_2O	.79
CYCLOPROPANE	C_3H_6	.52	OXYGEN	O_2	*.97
DIBORANE	B_2H_6	1.01	PENTABORANE	B_5H_9	.15
ETHANE	C_2H_6	.56	n-PENTANE	C_5H_{12}	.22
ETHENE (ETHYLENE)	C_2H_4	.69	PHOSPHINE	PH_3	.39
ETHYLENE OXIDE	C_2H_4O	.52	PROPANE	C_3H_8	*.52
FLUORINE	F_2	.93	SILANE	SiH_4	.36
FREON 11	CCl_3F	.36	SULFUR DIOXIDE	SO_2	.70
FREON 12	CCl_2F	*.36	SULFUR HEXAFLUORIDE	SF_6	.28
FREON 13	$CClF_3$	.46	TUNGSTEN HEXAFLUORIDE	WF_6	.23
FREON 14	CF_4	.60	URANIUM HEXAFLUORIDE	UF_6	.23
FREON 22	$CHClF_2$	*.43	WATER VAPOR	H_2O	.80
FREON 114	$CClF_2$	*.22	XENON	Xe	1.31

*Empirical data; others theoretical

+ Multiply air scale by correction factor

TABLE I

If the proportion of CO_2 were to increase to 20%

air, CO and NO	0.80 x 1.00 =	0.80
CO_2	0.20 x 0.73 =	0.146
		0.946

Change in calibration factor = $\frac{0.96 - 0.946}{0.96}$ = 0.0146 = 1.46%.

3.0 OPERATION OF THE PARTICULATE MASS MEASUREMENT INSTRUMENT

3.1 Power Connections

Power is applied to the gauge by plugging in the two power cords to 115 volt 60 Hz receptables capable of providing a minimum of 20 amperes. The one power cord supplies power to the Computer Unit and indirectly to the Sampling Unit through the interconnecting cable. All units are protected by individual 10-ampere circuit breakers.

Inside the Computer Unit, three power cords must be plugged into the WABER receptacle. These cords come from the HP 5376A Systems Programmer, the HP 5360A Computing Counter, and the HP 5055A Digital Recorder.

Inside the Flow Unit, three power cords must be plugged into another WABER receptacle. These cords come from the Hastings-Raydist AHL-5PX Mass Flowmeter, the Hastings-Raydist FC-1P Automatic Flow Controller, and the pump.

All of the HP equipment and the Hastings-Raydist equipment have front-panel switches for applying power to each of the respective units. It is recommended that all of these switches be kept in the "ON" position and that the gauge be turned on and off by using the circuit breakers on the back panels of the Computer Unit and the Flow Unit.

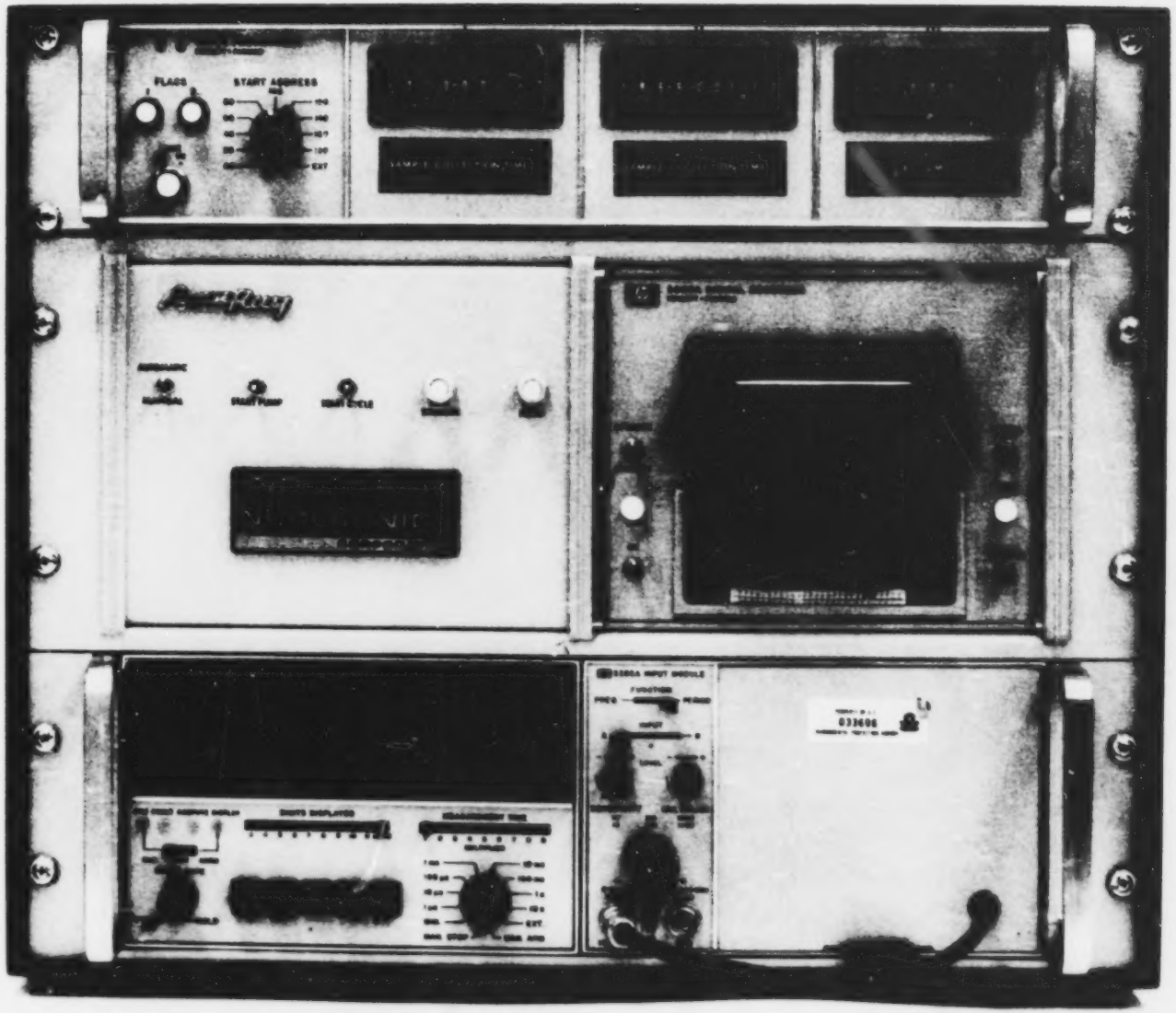
3.2 System Operation

3.2.1 Preparation for Start-Up

To prepare the gauge for operation, this procedure should be followed prior to turning on the main breakers in the back of the units (refer to Figure 7).

A. Computer Unit

1. HP 5376A Systems Programmer
   a. Depress LINE switch so that the unit is turned "ON" (unless previously left in this position as recommended in Section 3.1).
   b. Set the START ADDRESS to 00.
2. Controls
   a. The Manual-Automatic switch should be set in MANUAL for most operations. The significance of this setting is discussed in Section 3.2.4.
   b. The START PUMP switch is a momentary switch and will remain in its proper position.
   c. The START CYCLE switch is a momentary switch and will remain in its proper position.
3. HP 5055A Digital Recorder
   a. Turn the power switch to "ON" (unless previously left in this position).
   b. Set the OPERATE-STANDBY switch to OPERATE.
   c. Make certain there is enough pressure sensitive paper in the chamber to last for the day's recordings.



COMPUTER UNIT

Figure 7

4. HP 5360A Computing Counter

   a. Turn the POWER OFF - HOLD knob CCW as far as possible without its being off. (That is, starting from the extreme CCW position, turn CW until the unit just clicks on.)

   b. Set CYCLE RATE to MAX.

   c. Set DIGITS DISPLAYED to AUTO.

   d. Push the EXT switch.

   e. Set MEASUREMENT TIME (MULTIPLIER) to "1."

   f. Set MEASUREMENT TIME (KNOB) to "1 s."

   g. Set FUNCTION to PERIOD.

   h. Set INPUT to "A."

   i. Set LEVEL to full clockwise position.

   j. Set SENSITIVITY to "X1."

   k. Connect input (BNC connector) to Channel A.

   l. Set input coupling switch to DC.

B. Flow Unit (Refer to Figure 8)

   1. Place both front-panel power switches in their uppermost position.

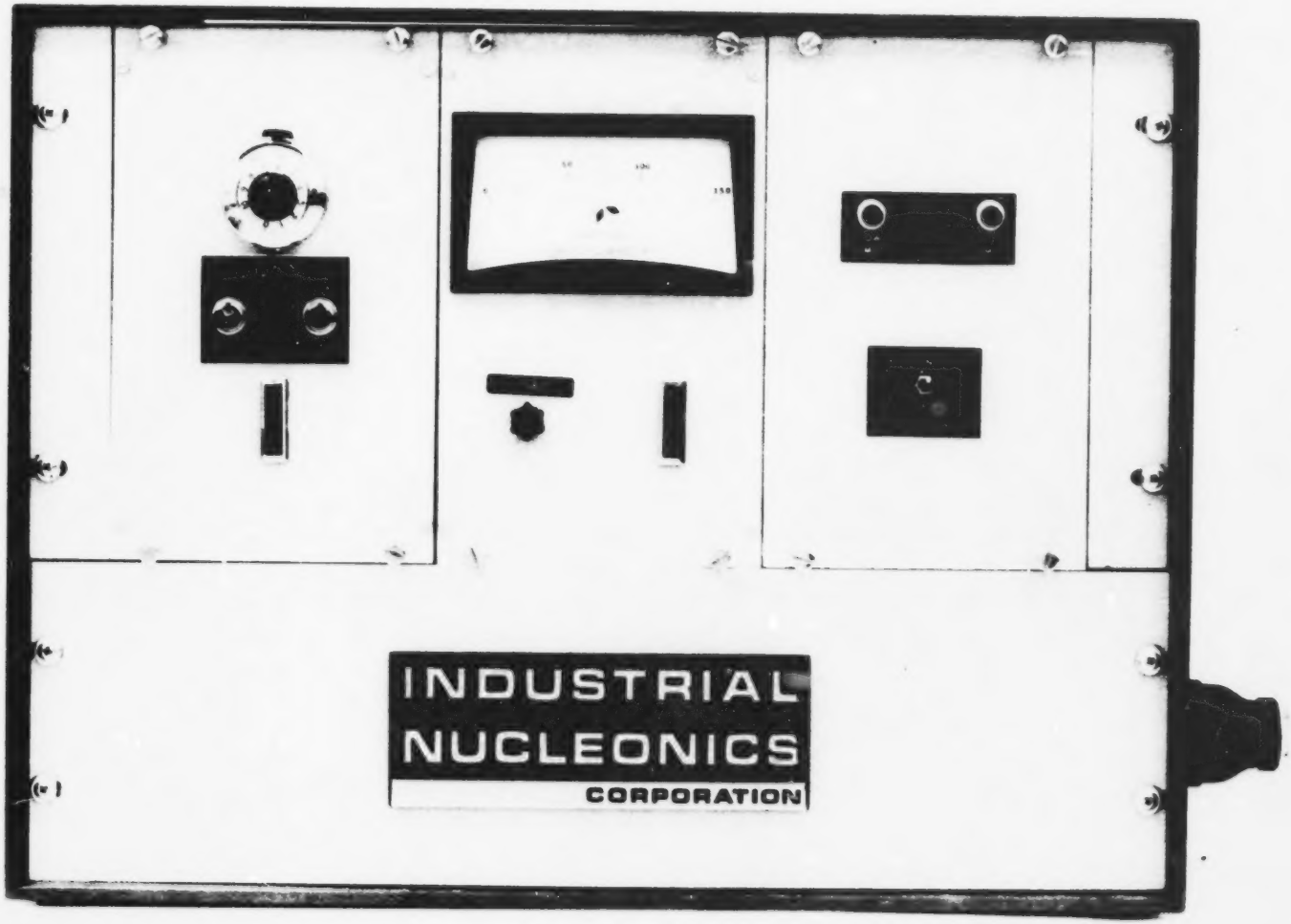
   2. Place the AUTO/MANUAL switch in AUTO.

   3. The INCREASE/DECREASE switch should be in its center position.

   4. Place the SET FLOW switch into its "OFF" position.

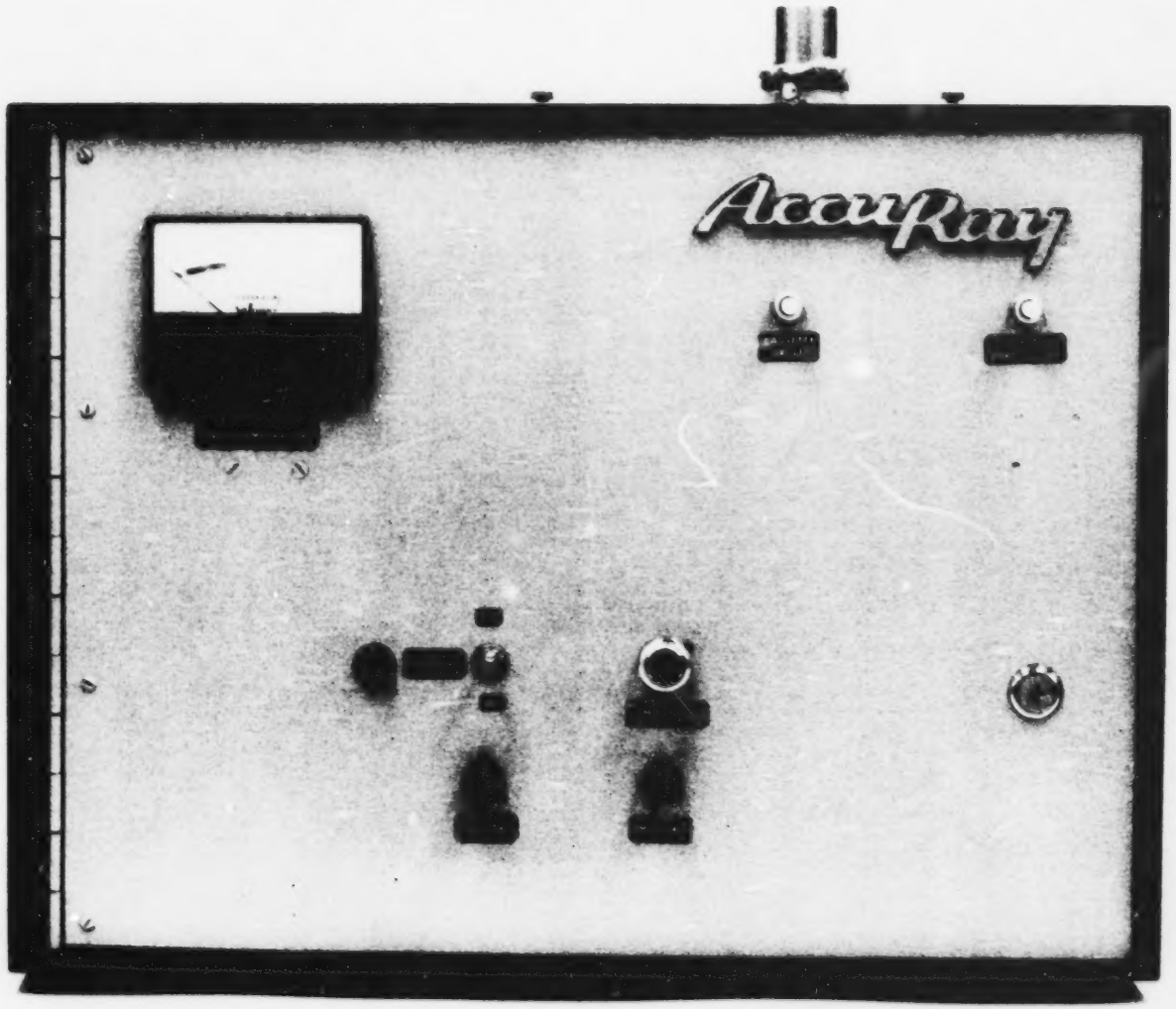
C. Sampling Unit (Refer to Figure 9)

   1. Set the HEATER switch at "OFF."



FLOW UNIT

Figure 8



SAMPLING UNIT

Figure 9

3.2.1.1 Internal Controls

Internal controls are described in this section. The unit has been delivered with all internal controls set properly and no control should be changed without a thorough understanding of its function.

D. Internal to the Computer Unit (Refer to Figure 10)

1. HP 5376A Systems Programmer

   a. There is a switch on the back of the HP 5376A Systems Programmer to allow a check on the program. This switch is labeled CHECK PROG and should be in "2" position.

   b. The program boards inside the HP 5376A should correspond to the program cycle desired. The first two boards are the only ones which change between Federal Cycle and Single Cycle (refer to Figure 11).

2. HP 5055A Digital Recorder

   a. SELECTOR should be in "115 volt" position.

   b. BLANKING should be in "ON" position.

   c. Code switch should be in "+8421" position.

3. HP 5360A Computing Counter

   The switches on the back of the counter should be set as follows.

   a. SCALER OUTPUT on "10^1."

   b. FREQ STD on "5 MHZ OUTPUT."

   c. TRIG/NORM on "NORM."

   d. Power on "115 volt."

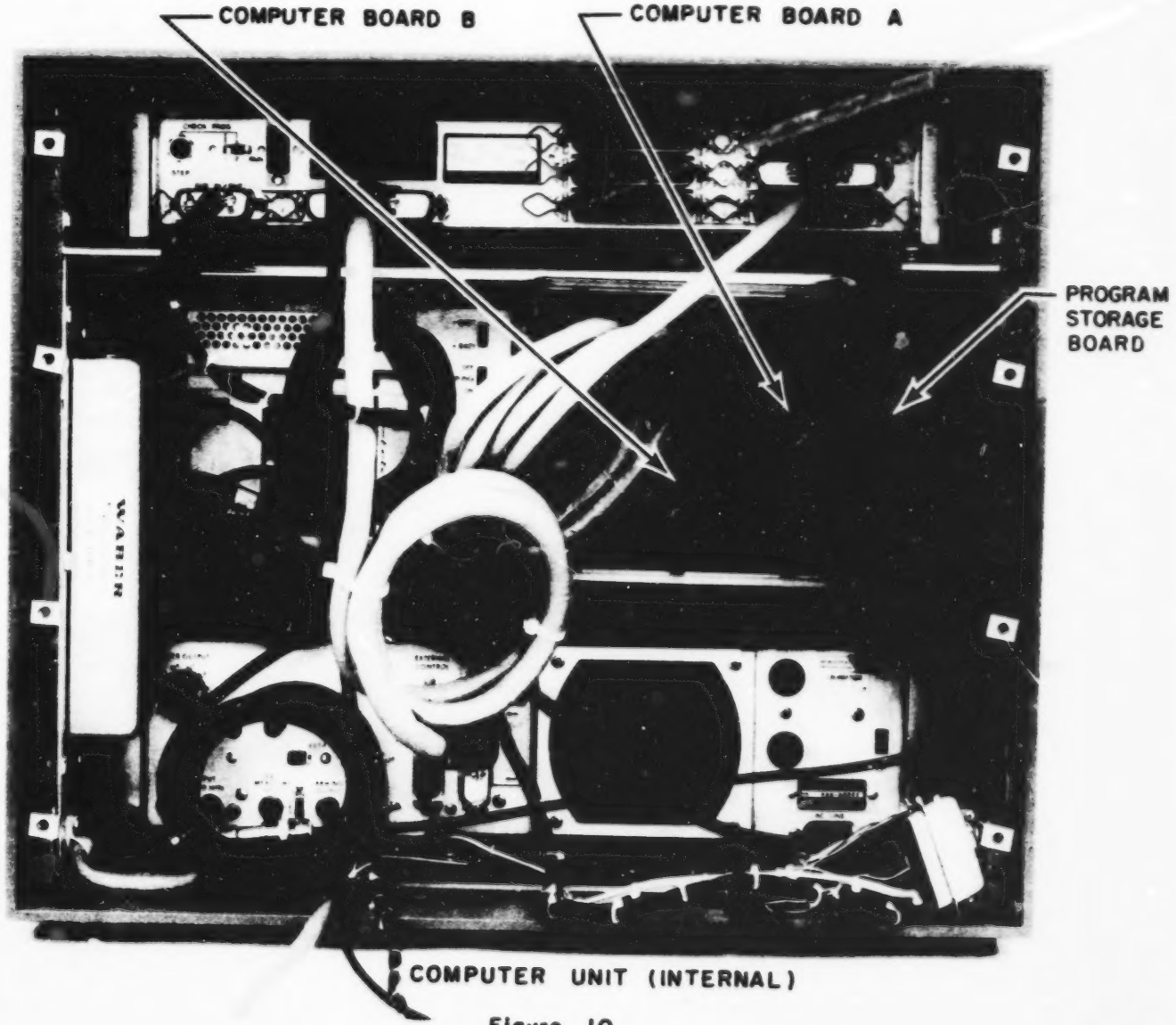
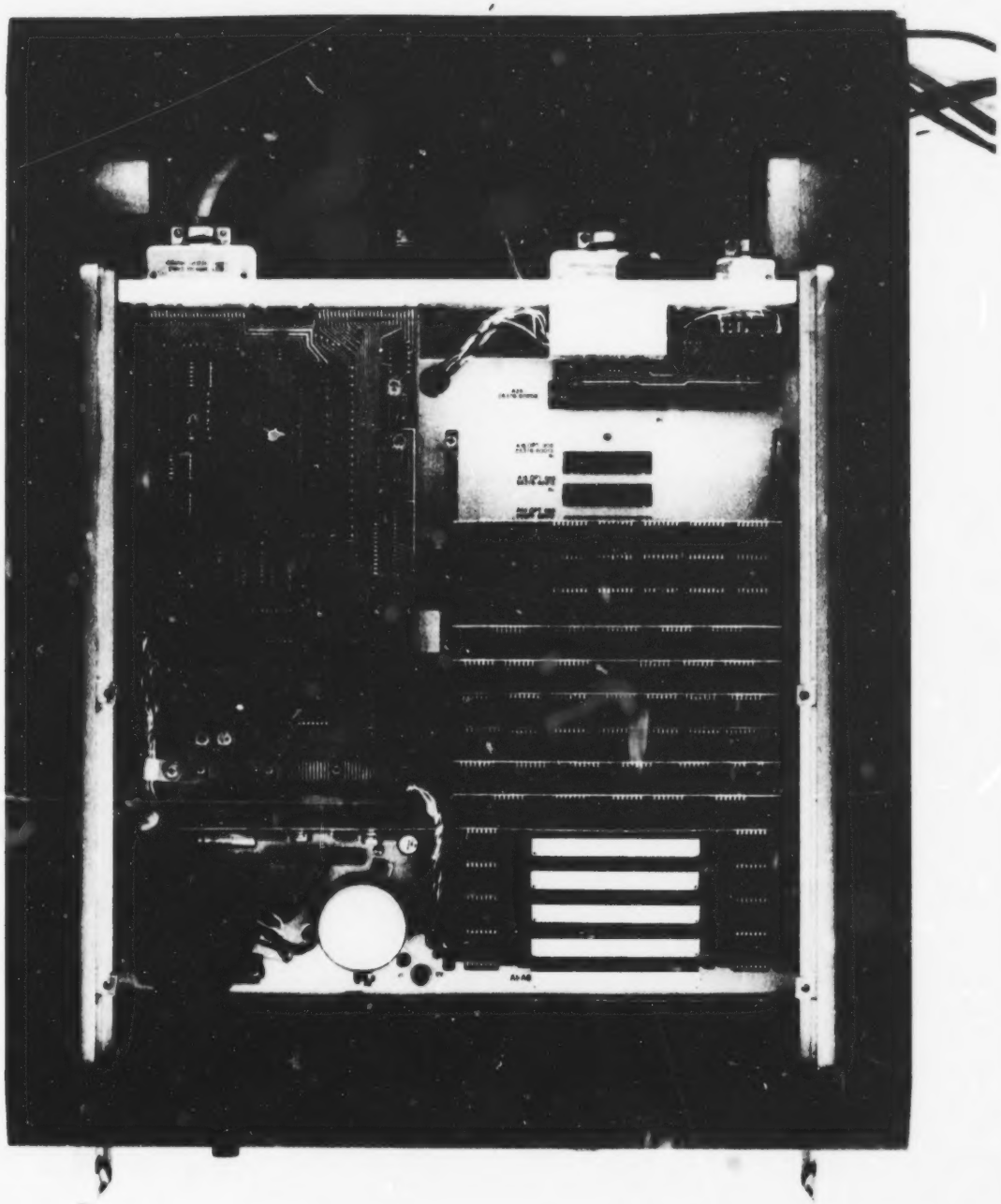

COMPUTER BOARD B
COMPUTER BOARD A
PROGRAM STORAGE BOARD
WARNING
COMPUTER UNIT (INTERNAL)

Figure 10



TOP VIEW OF HP 5376A SYSTEMS PROGRAMMER

Figure 11

E. Internal to the Sampling Unit (Refer to Figure 12)

1. Set TIME DELAY relay to 1/2 minute.
2. Set MOTOR switch to "ON" position.
3. Set DRIVE switches (LEFT and RIGHT) to "OFF."

F. Internal to the Flow Unit (Refer to Figure 13)

1. On back of the Auto Flow Unit, set the LOCAL/COMPUTER control to "COMPUTER."

3.2.1.2 External Conditions

External to the three units, the following should be performed.

G. Connect the 50-foot cable between the Computer Unit and the Sampling Unit and fasten the military connectors securely.

H. Connect the 25-foot cable between the Sampling Unit and the Flow Unit and fasten the military connectors securely.

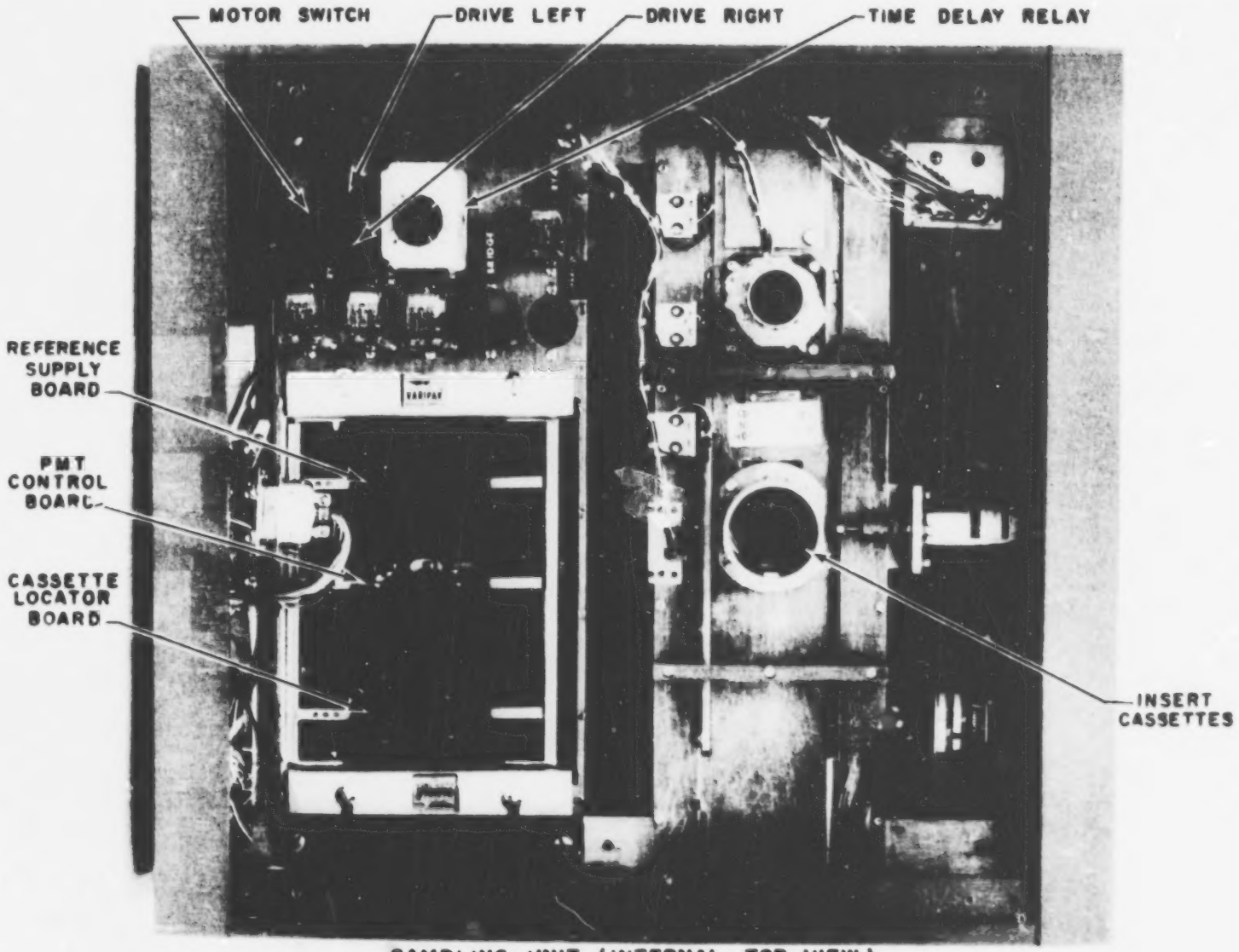
I. Connect the 20-foot piece of flexible tubing between the Sampling Unit and the Flow Unit.

J. Connect the power cord from the back of the Computer Unit to a 115-volt, 60-Hz, 20-ampere supply.

K. Connect the power cord from the back of the Flow Unit to a 115-volt, 60-Hz, 20-ampere supply.

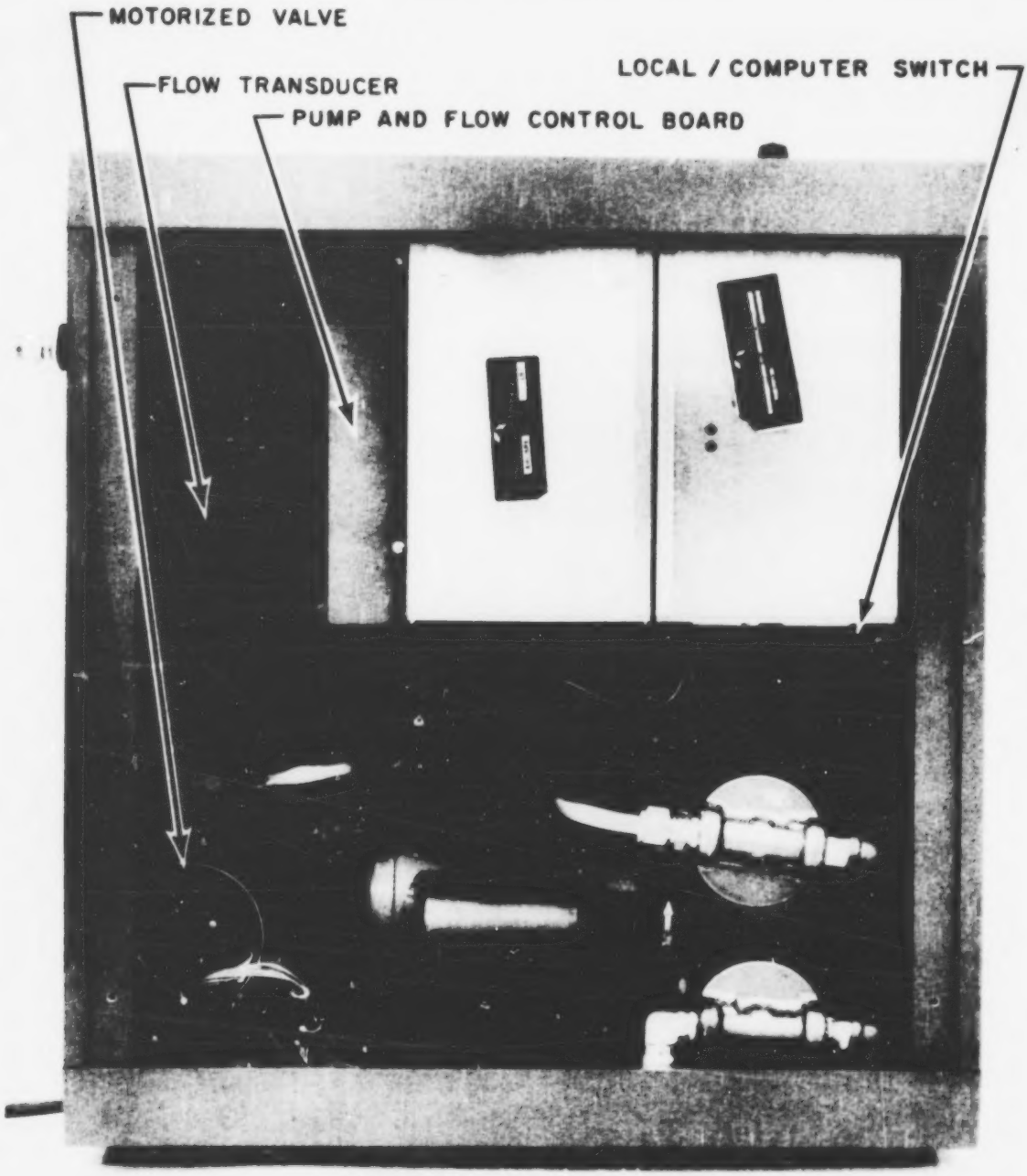
L. Place an adequate number of cassettes into the cassette holder.

M. Make sure the "rejected cassette" holder is empty.



SAMPLING UNIT (INTERNAL, TOP VIEW)

Figure 12



INTERNAL TO FLOW UNIT

Figure 13

3.2.2 Operation of Gauge (Federal Cycle)

To operate the gauge, this procedure should be followed once it is verified that the Federal Cycle program boards are in the Systems Programmer.

A. Place all back-panel circuit breakers on all three units to the "ON" position in the following sequence: Flow Unit, Sampling Unit, and Computer Unit.

B. Press and release the CLEAR-RESET switch two or three times on the front of the HP 5360A Computing Counter (Figure 7) immediately after turning on the Computer Unit. (The STANDBY light should come on.)

C. Wait 5 minutes after power is applied. (This is to allow the +12 volts to be applied to the relay system and the PMT to stabilize.)
During this wait period, several adjustments can be made in preparation for running.

D. Set the SAMPLE COLLECTION TIME I to desired pumping time in seconds (normally "+ 5.0500 x 10 + 2" for the Federal Cycle but can be varied significantly depending on the application).

E. Set the SAMPLE COLLECTION TIME II to desired pumping time in seconds (normally "+ 8.6600 x 10 + 2" for the Federal Cycle; this input has no bearing on Single Cycle but should always be positive).

F. Set X/QM to the appropriate factor for the Federal Cycle. (This input has no bearing on Single Cycle.)

G. Make certain there are enough cassettes in the loading magazine and sufficient paper in the printer for the anticipated run.

H. If inlet heating is desired, turn the HEATER (Sampling Unit) to "ON" and adjust the TEMP ADJUST potentiometer to the desired INLET TEMPERATURE. Lock the potentiometer. Allow time for the inlet to heat up.

I. Turn on the SET FLOW and adjust the SET POINT until the desired FLOW RATE is achieved. Lock the SET POINT potentiometer. (Note: neither limit light should be lit; if a light is lit, the flow control valve is at its extremity and the Flow Controller is not in its control range.) Turn off the SET FLOW switch.

The unit is now ready to process filters in preparation for collecting samples.

J. Make certain MANUAL/AUTOMATIC switch is in MANUAL for the Federal Cycle. Toggle the momentary START CYCLE switch. The carrier slide mechanism (CSM) is then incremented as follows:

   a. Move to position 3 and pick up a cassette B_1.
   b. Move to position 4 and pick up a second cassette A (Federal Cycle only).

c. Move to position 3 and standardize on cassette A for 200 seconds (Federal Cycle only).

d. Move to position 2 and standardize on cassette B_1 for 200 seconds.

e. Move to position 1. The HOLD light comes on at the beginning of the command to move to position 1. After position 1 is reached, all action stops. Cassette B_1 is now in position to collect sample. To collect sample B_1, proceed as follows.

K. Toggle the momentary START PUMP switch. The gauge collects sample for the length of time set into COLLECTION TIME I.

The CSM then moves to position 2 and (a) measures the sample on cassette B_1 for 200 seconds and (b) collects sample on cassette A for the length of time set into COLLECTION TIME II. The pump continues to run while the CSM moves to position 2. This is normal.

The CSM then moves to position 3 and measures the sample on cassette A for 200 seconds. The pump is disconnected during this period. (In moving to position 3, the CSM rejects cassette B_1 and picks up cassette B_2.)

Once this 200-second period is over, the CSM moves to position 2 to standardize on cassette B_2 for 200 seconds and then on to position 1. Again, the HOLD light comes on at the beginning of the command to move to position 1. After position 1 is reached, all action stops and cassette B_2 is in position to collect sample.

L. To resume gauge action, the momentary START PUMP switch must be toggled. To calculate the time required to wait for this toggle of the START PUMP, the last 400 seconds used up to measure cassette A and standardize cassette B_2 must be accounted for. That is, if the required wait is 10 minutes (600 seconds), then only a 200-second wait (600 - 400 = 200) should occur after the HOLD light comes on. (The time from automatic halting of the pump and manual toggling of the START PUMP is the full 10 minutes.)

Following this toggle of the START PUMP, a sample is collected on cassette B_2 for a time equal to that set into COLLECTION TIME I (normally "+ 5.0500 x 10 + 2"). After the required sampling time, the pump is disconnected and the CSM moves to position 2 to measure on cassette B_2 for 200 seconds.

Once the printout of all data regarding this Federal Cycle is complete, the CSM moves to position 3, rejects

cassette B_2, picks up a new cassette B_1, moves on to position 4, rejects cassette A, and picks up a new cassette A. The CSM then moves from position 4 to position 1, stopping at positions 3 and 2 for standardizations, and holds at position 1 ready to begin a new Federal Cycle. In this HOLD mode, the gauge is ready for another Federal Cycle. As soon as the next exhaust is connected, the momentary START PUMP switch can be toggled to start the sequence.

If there are problems during a Cycle of the gauge, the CLEAR/RESET button on the HP 5360A Computing Counter should be pushed. Another cycle can be initiated by depressing the Start Cycle switch.

Under certain circumstances, it may be desirable to abort a pumping sequence and retain the data collected up to that point. This can be done by momentarily turning the sign for SAMPLE COLLECTION TIME II from "+" to "-". As soon as the printer prints the flow data, the sign must be immediately returned to "+" prior to automatic initiation of the beta measurement sequence or the beta measurement is also aborted. This feature must be utilized with extreme caution to avoid incorrect data. It is suggested that several "practice" runs be made without any cassettes in the unit to develop familiarity with the procedure. This feature is

almost always used only in the Single Cycle, and in that situation the pump time which is printed is the actual pumping time. That is, if a pump time of 3600 seconds were dialed in but aborted at 1840 seconds, the time printed would be 1840 seconds.

If there are no more Cycles to be run, the gauge may be turned off by moving all three back-panel circuit breakers to their "OFF" positions in any sequence.

If it is desired to change the Cycle (Federal vs. Single), the HP 5376A Systems Programmer should be turned "OFF" while the two programmer P.C. boards in the HP 5376A Systems Programmer are changed. After the change is completed, the HP 5376A Systems Programmer should be turned "ON" and the CLEAR/RESET button immediately depressed two or three times.

3.2.3 Operation of Gauge (Single Cycle)

To operate the gauge, this procedure should be followed once it is verified that the Single Cycle program boards are in the Systems Programmer.

A. Place all back-panel circuit breakers on all three units to the "ON" position in the following sequence: Flow Unit, Sampling Unit, and Computer Unit.

B. Press and release the CLEAR/RESET switch two or three times on the front of the HP 5360A Computing Counter (Figure ~) in the Computer Unit. (The STANDBY light should come on.)

C. Wait 5 minutes after power is applied. (This is to allow the +12 volts to be applied to the relay system and the PMT to stabilize.)

D. If inlet heating is desired, turn the HEATER (Sampling Unit) to "ON" and adjust the TEMP ADJUST potentiometer to the desired INLET TEMPERATURE via the front-panel chart. Lock the potentiometer. Allow time for the inlet to heat up.

E. Turn on the SET FLOW and adjust the SET POINT until the desired FLOW RATE is achieved. Lock the SET POINT potentiometer. (Note: neither limit light should be lit; if a light is lit, the flow control valve is at its extremity and the Flow Controller is not in its control range.) Turn off the SET FLOW switch.

F. Turn the SAMPLE COLLECTION TIME I to desired sampling time in seconds.

G. Verify that the sign of SAMPLE COLLECTION TIME II is positive.

H. Make certain there are sufficient cassettes in the loading magazine and sufficient paper in the printer to complete the run.

The unit is now ready to process a filter in preparation for collecting samples.

I. Toggle the momentary START CYCLE switch (for AUTOMATIC operation, no further operator action is required). The carrier slide mechanism (CSM) is then incremented as follows:

a. Move to position 3 and pick up a cassette B.

b. Move to position 2 and standardize on cassette B for 200 seconds.

c. Move to position 1. The HOLD light comes on at the beginning of the command to move to position 1. After position 1 is reached, all action stops. Cassette B is now in position to collect a sample. To collect sample B, proceed as follows.

J. Toggle the momentary START PUMP switch. The gauge collects sample for the length of time set into COLLECTION TIME I. The gauge then moves the CSM to position 2 and measures the sample on cassette B for 200 seconds.

The CSM then moves to position 3 and ejects cassette B. The next command is to move the CSM to position 2 to standardize the new cassette B' for 200 seconds.

Finally, the CSM moves to position 1 and holds, ready to collect sample on cassette B'.

3.2.4 Manual vs. Automatic

The usual position of this switch for gauge operation is MANUAL. In this position, the gauge halts (HOLD) when it comes to position 1. Operation continues when the START PUMP switch is toggled.

In automatic position in the Federal Cycle, the gauge continues to cycle through the "three cassette" sequence without stopping. Thus, the time separation between the second and third collection is 6.67 minutes (400 seconds) instead of 10 minutes. Also, the gauge automatically goes into the next set of three cassettes. [This can be changed in the program so that after a set of three cassettes the gauge returns to STANDBY and stops.]

In automatic position in the Single Cycle, the gauge continues to cycle through the "one cassette" sequence without stopping.

3.2.5 Ejection of Cassettes

It is possible that further studies on the particulate collected by the gauge may be necessary. Therefore, it is important to know the order in which the cassettes are ejected from the gauge.

In the Federal Cycle, the cassettes are ejected in the following order: $B_1(Y_1)$, $B_2(Y_3)$, and $A(Y_2)$. Therefore, in extracting three cassetttes from the unit following a Federal

Cycle, the top cassette is A, the middle cassette is B_2, and the bottom cassette is B_1.

In the Single Cycle, only one cassette is involved; therefore, there is no uncertainty as to which cassette is which. The bottom cassette is the first one processed, and the top cassette is the last one processed.

3.3 Computer Organization

The computer controls all phases (both mechanical and electrical) of the gauge. This includes CSM position (as previously discussed), all pumping operations, data collection, and data processing. The information presented to the operator by the computer is in standard engineering terms. This requires manipulation of the raw data (in counts per second) to meaningful information in mass or mass per volume units.

The particulate concentration in a gas sample is determined from the change in areal density of a filter due to particulate deposition. This measurement is accomplished by observing the change in areal density between (a) a standardize measurement on a clean filter and (b) a measurement after deposition of particles. In the Federal Cycle the particulate densities on three filters are required. Once these are known the computer calculates a composite of the three, and an overall evaluation of the particulate concentration is then available.

During the STANDARDIZE and MEASURE time intervals, the computer accumulates a number of counts N_S and N_M, respectively, from the photo-multiplier tube (PMT). After the data collection is complete, the computer makes a MASS computation from N_S and N_M:

$$\text{MASS} = Y_1 = 8.87 \times 10^3 \text{Ln}\left(\frac{N_S}{N_M}\right) \text{ micrograms}$$

After three such calculations are made, the computer calculates a Y which is the composite of Y_1, Y_2, and Y_3 according to

$$Y = (0.43\ Y_1 + 0.57\ Y_2 + Y_3)$$

For the Single Cycle, the MASS is determined as before. During the pump sequence, however, the analog flow information to maintain closed loop control is converted via a voltage-to-frequency converter to digital pulses which are collected by the Computer Unit. The total pulses collected (N_F), then, represents the total integrated flow through the filter. Thus:

$$\text{VOLUME} = K\ N_F \text{ cubic meters}$$

where K is a constant to relate units, and

$$\text{CONCENTRATION} = \frac{\text{MASS}}{\text{VOLUME}} \quad \frac{\text{micrograms}}{\text{cubic meter}} \ .$$

Both these quantities are printed, along with the actual duration of the pump time (in seconds).

The Computer equipment used in the gauge uses diode package construction for programming. The actual program that is in the gauge appears in Appendix A. The state of the program can be verified at any time by manually stepping the program (by placing the PROGRAM switch in Run 1 and pushing the STEP button) and observing the Computing Counter Nixie display. The program is included in this operating manual so that the gauge operator can verify the state of the program. For additional information on the details of how to check the program, the reader is referred to the Hewlett-Packard Systems Programmer Handbook-5376A (included, by reference, in this manual).

3.3.1 Federal/Single Cycle Modes

The particular cycle in which the gauge is operating is determined exclusively by the first two program P.C. boards (address location 0 through 79) shown in Figure 11. These two P.C. boards are the only ones of the total of five that are to be changed. The two boards that are not in use for a given mode are housed in a compartment in the top back of the Computer Unit. In this manner they are always available, and a cycle change can be made in a matter of minutes. Boards 3 through 5 are utilized in both cycles and must be in place at all times.

3.4 Schematics

Schematics showing the circuitry built into the gauge appear in Appendix B of this manual. These schematics are on ten drawings and are listed below:

a. PMT Control
b. Computer Interfacing
c. Cassette Locator
d. Pump and Flow Control
e. Flow Signal
f. Internal Wiring (Computer Unit)
g. Internal Wiring (Sampling Unit)
h. Internal Wiring (Flow Unit)
i. Overall Interconnection Diagram
j. Gear Motor and Heater Supply

Some key segments of the circuitry are described below.

3.4.1 Automatic Gain Control (Part of PMT Control)

The PMT control circuitry shows essentially all of the circuit aspects associated with the PMT operation.

A preamp for amplifying the small signals from the PMT is housed in a totally enclosed metal shielding box and is permanently mounted to the PMT housing. Output signals from the preamp are coupled to a threshold detector which is also contained in a totally enclosed metal shielding box. Total

shielding of these circuits is provided to maintain isolation between logic-level signals and the low-level signals provided by the PMT.

Signals from the threshold detector are passed to the printed circuit (P.C.) card rack (Figure 12) for further processing. These signals are connected to pins 14 and 15 of the Signal Logic Board.

Other signals are taken from pins 12 and 13 of the Signal Logic Board and further processed by the PMT Control Board. This Board provides an output voltage on pins 4 and 6 which is used to drive a proportional high voltage supply (MIL associates model SSP-1500). The proportional high voltage supply is contained in a separate totally enclosed shielded box along with appropriate filtering for the high voltage. The high voltage is connected to the PMT assembly through a coaxial cable.

The PMT operating voltage is automatically adjusted to an appropriate level by the action of the AGC circuit. This voltage is typically 1000 to 1050 volts.

If precision measurements are to be made, it is desirable that the gauge be turned on for 15 to 30 minutes prior to initiation of the measurement. This time allows all components of the AGC system to stabilize at their appropriate operating conditions.

3.4.2 Computer Interfacing

At appropriate times as the gauge proceeds throughout the program, solenoids and lights to indicate the status of the gauge are energized. As commands are issued by the Computer, the Computer is halted until signals are returned to the Computer to indicate that the action required of the command has been accomplished.

3.4.3 Cassette Locator

The Cassette Locator Board (a) receives the desired position information from the computer, (b) converts this information into the correct polarity signal for drive to the motor based on the slide mechanism's present position, (c) checks to see that the correct position is achieved, and (d) when the correct position is reached, sends a signal back to the Computer Interface Board saying that the cassette is in the proper position as asked for by the Computer.

3.4.4 Pump and Flow Control

The Pump and Flow Control Board contains the logic necessary to sequence the pump and the flow. Since the flow control is automatic, it is necessary to initiate the pump prior to the flow controller and turn off the flow controller prior to the pump. This is done so that the controller does not automatically try to maintain the flow when the pump turns off and therefore be at the end of its drive when the pump

comes on. This would only cause a delay in achieving the desired flow and would not harm the gauge in any manner other than to reduce accuracies.

3.4.5 Flow Signal

The flowmeter used in the gauge provides a D.C. level indicative of mass flow of the gases passing through the filter. The Flow Signal Board contains a voltage-to-frequency converter which provides the necessary pulse information to enable the Computer to measure the flow.

3.4.6 Additional Schematics

The remaining schematics show the wiring internal to each unit and the interconnections between each unit. These show the pin numbers on P.C. boards, power supply connections, and wiring for the gearmotor and heater supplies.

Each of the primary power supplies is fused on its output. These fuses are mounted on the back of the Sampling Unit.

3.5 Selection of a Filter Medium

This unit has been carefully engineered to permit the use of a variety of filter media with a minimum of disturbance to the media by the clamping and pumping processes. There are, however, certain characteristics which, if possessed by the medium, greatly enhance the accuracy and repeatability of results. Features such as low basis weight (areal density), low flow

resistance, uniform areal density within an individual filter, low moisture sensitivity, high tensile strength, and high resistance to permanent damage after slight deformation are all important. Specific applications may put more emphasis on some of these features than others. Mobile source monitoring, for example, requires low moisture sensitivity, while ambient monitoring requires low flow resistance.

The maximum flow rate achievable with a given filter is a function of three parameters: filter resistance, pump capacity, and effective sample area. The pump capacity achievable with the type of pump used in this unit is linear with vacuum pulled and has been experimentally determined to be:

$$Q = \frac{173}{63}(63 - x) \text{ liters/minute} \qquad (1)$$

where x is the vacuum pulled in centimeters of mercury. The flow rate achievable with a given filter is also linear with vacuum and is

$$Q = AR\frac{x}{70} \text{ liters/minute} \qquad (2)$$

where x is previously defined, A is the effective sample area and R is the flow rate in liters per minute per square centimeter achievable with a given filter at 70 centimeters of mercury. Eliminating x from these equations and solving for Q:

$$Q = \frac{173\ AR}{192.22 + AR} \text{ liters/minute} \qquad (3)$$

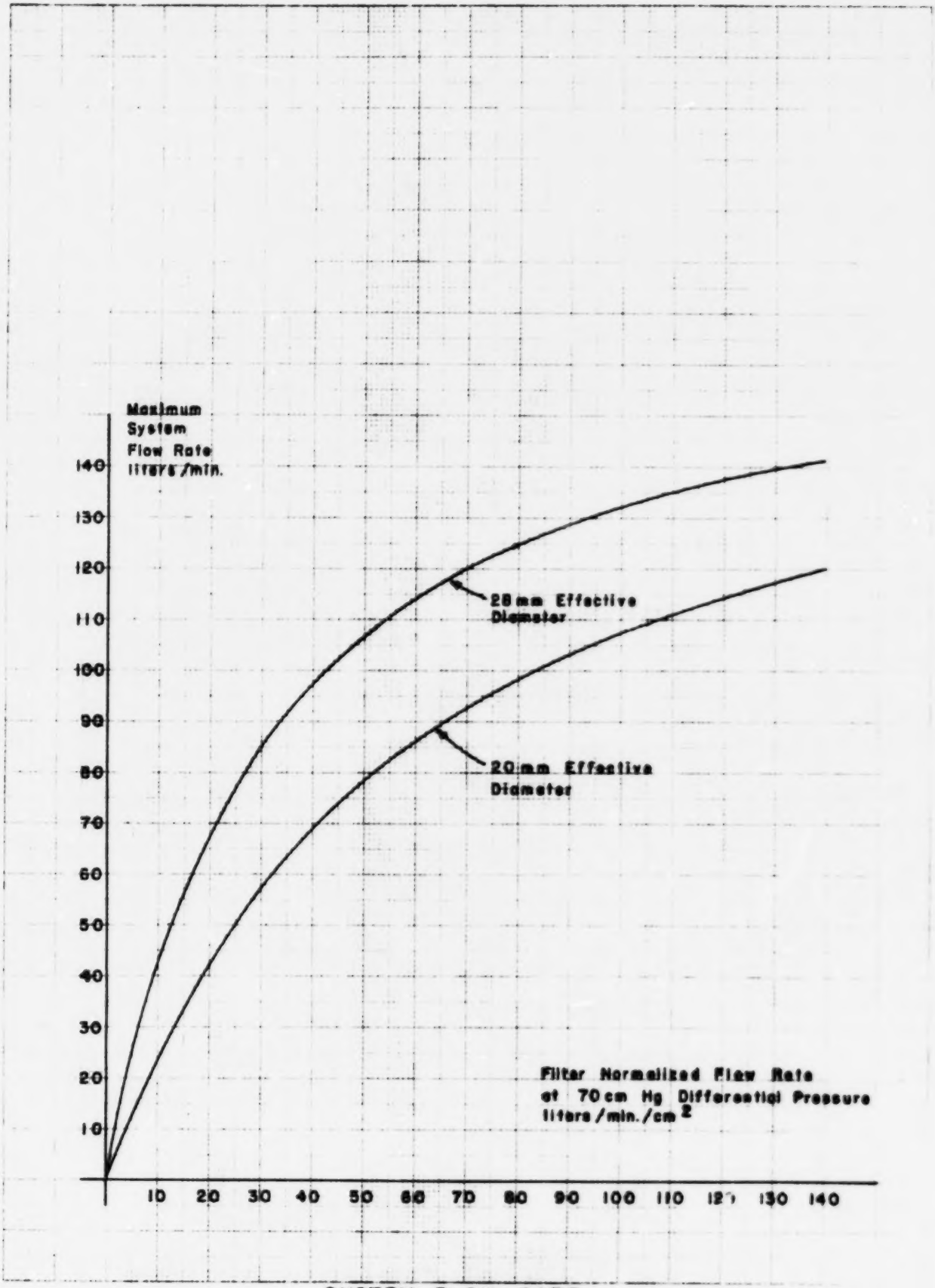
The effective area A for this unit as delivered is 3.14 cm^2. Thus for a 20 mm effective diameter, equation (3) reduces to

$$Q_{20} = \frac{173R}{61.22 + R} \qquad (4)$$

For a 28 mm effective diameter, equation (4) becomes

$$Q_{28} = \frac{173R}{31.23 + R} \qquad (5)$$

Both equations (4) and (5) have been plotted and are shown in Figure 14. To find the system flow rate for a given filter, locate the filter normalized flow rate at 70 cm Hg on the horizontal axis and refer to the curve for the appropriate area. Gelman Type A Glass Fiber material has a stated flow rate of 60 liters per minute per square centimeter at 70 centimeters of mercury. For the 20 mm effective diameter, this results in a system flow rate of 86 liters per minute; for a 28 mm diameter, a system flow rate of 114 liters per minute can be achieved. It should be stated that the curves in Figure 14 indicate the maximum system flow rate which can be achieved; almost any lesser flow rate can also be achieved through the flow controller.



SYSTEM FLOW RATE

Figure 14

3.6 Cassette Preparation

The filter medium is mounted on the topside of the cassette by means of a multifingered spring clip. Some care must be taken in preparation of the cassette to avoid contact with the medium. Oil from the hands is measured during the standardization cycle and could potentially be volatilized during the pump cycle, thus introducing an error. If the cassette is laid aside after assembly and prior to use, the filter side of the cassette must be up.

In some cases where it is desired to operate the instrument at its maximum sensitivity, it may be necessary to process the cassettes in the following manner: (a) prepare cassette in above manner; (b) bake cassette at 100°C in clean oven for 10 minutes; (c) if cassette is not to be used right away, store in container filled with desiccant; (d) before use, remove cassette from container and allow to stabilize for thirty minutes or longer in room in which it is to be used. This procedure is necessary to prevent errors introduced by gain or loss of moisture during pumping. If the filters have been exposed to a higher humidity than the sample of interest, failure to follow the bake-out procedure may result in a weight loss (due to evaporation) during the pump cycle. This should not be a problem unless the higher humidity is greater than 75%.

Correspondingly, if the room humidity is low (0 - 40%) and the humidity of the sample is greater than 75%, it may be necessary to follow steps (a), (b), and (c) above but then precondition the filters in a humidity environment which closely matches the humidity of the sample just prior to use.

To reiterate, the above procedure is only necessary to achieve high accuracy at maximum sensitivity. Typical weight losses are on the order of 70 micrograms. If this is too low to be of interest, the procedure is not necessary. Further, if a filter medium is used which does not exhibit moisture adsorption/desorption characteristics, the procedure may be dropped altogether.

3.7 Calibration

Should it ever become necessary to check the calibration of the unit, the Federal Cycle cards must be in the computer. In addition, three test cassettes (two of which are empty and one which is loaded with a medium of known areal density) must be utilized and these are supplied with the unit. To check the "zero" and "span" of the instrument, follow the procedure below:

a. Press the CLEAR/RESET. The STANDBY light should come on.

b. Remove all cassettes from the loading magazine.

c. Turn the Flow Unit "OFF" by using the circuit breaker on the back of that unit.

d. Place the two empty cassettes in the loading magazine.

e. Set COLLECTION TIME I to +5.0000 x 10 + 0 and COLLECTION TIME II to +2.0500 x 10 + 2.

f. Set all other controls on the Computer Unit for a normal collection cycle (see Sections 3.2.1 and 3.2.2).

g. Depress the CLEAR/RESET two or three times. The STANDBY light should come on.

h. Make certain the AUTOMATIC/MANUAL switch is in MANUAL.

i. When the unit is in STANDBY and all controls are properly set, depress the momentary START CYCLE switch and allow the unit to standardize the two empty cassettes.

j. When standardization is complete, the unit should halt in the HOLD position and the HOLD light should be on.

k. Refer to Figure 2. The cover over position 5 may be removed by removing the two thumb screws holding the cover on. Remove the cover and lay aside momentarily. There should be an empty

cassette in the cassette transfer mechanism directly under this cover.

l. Remove this empty cassette and replace it with the cassette loaded with a material of known areal density supplied with the unit. The total mass to be printed using this cassette is indicated on the cassette itself.

m. Replace the cover over position 5.

n. Depress the momentary START PUMP switch and allow the unit to proceed.

o. The empty cassette which was left in the pump position will be clamped for a period of 5 seconds. The CSM then moves this empty cassette to the measurement position, collects a count for 200 seconds, and prints the mass (Y_1 in the Federal Cycle). Since this cassette is empty the indicated mass should be less than 30 micrograms. This checks the "ZERO" of the unit.

p. As soon as Y_1 is printed, the CSM then moves the loaded cassette into the measurement area and collects a count. Since the standardization for this measurement was on an empty cassette, the indicated mass Y_2 is the areal density

of the filter multiplied by the effective area. This checks the "SPAN" of the unit, and the calibration check is complete.

q. As soon as Y_2 is printed, depress CLEAR/RESET two or three times.

r. Depress START CYCLE to reject all the cassettes used in the calibration check and remove these cassettes from the holding magazine.

s. Depress CLEAR/RESET again two or three times and then return the COLLECTION TIME switches to their normal setting.

t. Reload the loading magazine with fresh cassettes.

u. Turn on the Pump Unit by using the breaker in the back of that unit. Wait a short period to allow the flowmeter electronics to stabilize.

v. The unit is now ready to resume testing by depressing the START CYCLE switch.

NOTE: When handling the calibration cassettes, care must be exercised to avoid contaminating the sample by touching the surfaces or allowing the cassettes to remain in an open area for any period of time. This will introduce errors not associated with a change in calibration.

4.0 PREVENTIVE MAINTENANCE

4.1 Yearly Maintenance

Check the muffler filters for dirt accumulations. If they appear to be excessively dirty, remove them and rinse out the elements with trichloroethane or "safety solvent."

5.0 PRECAUTIONS IN HANDLING THE SOURCE

The source used in the Particulate Mass Measurement Instrument is a license-exempt quantity (100 microcuries) of Carbon 14. However, it is still important to handle the source with caution. For a low-energy beta source like Carbon 14, the most sensitive part of a human body will be the eyes. Therefore, if it ever should become necessary to handle the source, the following precautions are recommended:

a. Installation and removal of the source should be done by a qualified individual.
b. The source should be wipe-tested before handling.
c. The face of the source should not be touched with bare hands.
d. A pair of safety glasses should be worn to protect the eyes.
e. The face of the source should be kept at a distance of at least one foot when observing with bare eyes.
f. When disassembled, the source should be laid facedown or covered with any sheet material of 1/32" thickness.

As a part of the requirements under which this gauge is distributed, disposal of the source must be done by the

manufacturer. If, at any time, the gauge is to be disposed of, it should be returned to the manufacturer for proper disposition of the source.

6.0 TROUBLESHOOTING

The gauge is designed with numerous checks and balances to avoid possible difficulties in operation. For instance each time the computer commands certain gauge functions, it waits until the required task is completed and a response is returned before it proceeds to the next program step. Some of these responses are electronic in nature and simply indicate that a correct command was decoded out of the 1-of-16 decoder. [Note that this is necessary for instance (a) to avoid additional microswitches in the gauge to indicate linear travel or (b) to avoid placing a generator on the pump motor to indicate rotation motion when the pump is given a turn-on command.]

The exception to the above electronic return is in the operation of the carrier slide mechanism. When the computer asks the CSM to go to a position "X," the CSM moves in the proper direction to get there as indicated by three microswitches (nonprecise location). Only when one of the four locations is reached does the Cassette Locator Board check to see that the CSM is in the proper location as indicated by the locate microswitch (precisely located). If in the proper location, the Cassette Locator Board then gives a return command to the computer.

6.1 Operations Indicated by Lights

There are six lights on the gauge to indicate the status of the gauge. In case of sequencing malfunctions, the

two lights on the Computer Unit indicate the type of deviation from normal operation. The STANDBY indicates that the CLEAR/RESET has been pushed. To resume sequencing, the START CYCLE switch should be toggled.

The HOLD light indicates that the CSM has come to position "1." To resume sequencing, the START PUMP switch should be toggled.

The CASSETTE DRIVE light on the Sampling Unit indicates that the computer has given a command to the Cassette Locator Board to move to position "X." The light will be on while drive is applied. When the CSM gets to the Locate Microswitch, the light will extinguish while a check is made to see that the proper position is indeed reached. If this is not the proper position, drive will again be applied until the proper position is reached.

The COLLECTING PARTICULATE light will come on while the gauge is actually collecting particulate. This is not nessarily synonymous with the pump motor running. That is, in the Federal Cycle between the first two sample collections, the pump remains on while the cassette is transferred.

Should any of the above four lights come on in disagreement with the normal sequence of the program, false commands are entering the system. The CLEAR/RESET button should be pressed and the cycle started anew.

The other two status lights are located on the Flow Unit and are labeled HIGH LIMIT and LOW LIMIT. These indicate the status of the motorized valve. In the event that either of these two lights are lit, the motorized valve is at the end of its travel and the flow is no longer being automatically controlled. Checks should be made for system air leaks. Also the SET POINT should be checked for the correct setting.

6.2 Computer Program Check

By use of the CHECK PROG and the STEP switches located on the rear of the HP 5376A Systems Programmer, the operator can check the status of the program in the Computer. The reader is referred to the Systems Programmer Handbook for additional information in becoming acquainted with the use of this aid in servicing the gauge.

6.3 Additional Checks

It is assumed that when a problem is encountered, the first things that will be checked are (a) the three circuit breakers on the three individual units are "ON," (b) the "ON-OFF" switches on all equipment are turned "ON," and (c) that no fuses are "blown."

Also check that the connectors on the interconnect cables are securely tightened. Once this is done, an operator familiar with the gauge should be able to follow the particular cycle (Federal or Single) through the gauge operations and locate the point at which the gauge deviates from the program.

By locating the problem in this manner, clues are obtained as to where false signals are entering the system.

APPENDIX A

COMPUTER PROGRAM

Federal Cycle

5376A PROGRAMMING FORM

ADDRESS	INSTRUCTION SYMBOL	CODE	WORKING STORAGE x	WORKING STORAGE y	WORKING STORAGE z	STORAGE REGISTERS
0	EXT	12				Stand-by. Reset all solenoids.
1	(15)	37				($START CYCLE to continue)
2	Clr Data	16				
3	2	22				
4	EXP 2	22				
5	<15;↔	25	200			
6	Data ↔ x	71				
7	(4)	24				200
8	EXT	12				Seek position 3 (wait 1 sec)
9	(4)	24				
10	EXT	12				Seek position 4 (wait 1 sec)
11	(6)	26				
12	EXT	12				Seek position 3 (wait 1 sec)
13	(4)	24				
14	GO SUB	13				
15	8	30				
16	3	23				
17	1	21	N_{AS}			
18	Data ↔ x	71				
19	(1)	21				N_{AS}
20	EXT	12				Seek position 2 (wait 1 sec)
21	(2)	22				
22	GO SUB	13				
23	8	30				
24	3	23				
25	1	21	N_{BiS}			
26	Data ↔ x	71				
27	(2)	22				N_{BiS}
28	EXT	12				Seek position 1 and Hold (in MANUAL)
29	(0)	20				($START PUMP to continue)
30	EXT	12				Clamp solenoid; energize pump
31	(1)	21				energize switch valve
32	Clr xyz	76				
33	INT ↔ x	61				
34	Data ↔ x	71				From thumbwheel #1
35	(6)	26	505			
36	GO SUB	13				
37	2	22				
38	4	24				
39	1	21	N_{air}			

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5376A PROGRAMMING FORM

ADDRESS	INSTRUCTION SYMBOL	CODE	WORKING STORAGE x	WORKING STORAGE y	WORKING STORAGE z	STORAGE REGISTERS
40	EXT	12			Release switch valve; release clamp	
1	(3)	23			(wait 1 sec)	
2	EXT	12			Seek position 2 (wait 1 sec)	
3	(2)	22				
4	Data $\overrightarrow{xy}$	73	0,-1			
5	(5)	25				
6	IFx<0	11				
7	EXT	12			Turn off pump	
8	(5)	25				
9	IFx<0	11				
50	GO TO	17				
1	6	26				
2	5	25				
3	0	20				
4	EXT	12			Energize switch valve; energize clamp	
5	(7)	27				
6	GO SUB	13				
7	8	30				
8	3	23				
9	1	21	N_{BiM}			
60	Data $\overrightarrow{xy}$	73				
1	(2)	22	N_{BiS}	N_{BiM}		
2	GO SUB	13				
3	9	31				
4	6	26				
5	1	21	Y_i			
6	Data $\overrightarrow{xy}$	73	0,-1	Y_1		
7	(5)	25				
8	IFx<0	11				
9	GO TO	17			Sum the masses	
70	9	31				
1	1	21				
2	1	21				
3	y ↔ x	65	Y_1			
4	0	20				
5	3	23				
6	4	24			EPA constant "a" = 0.43	
7	EXP 1	21				
8	<15,-+	21				
9	x	57	aY_1			

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5376A PROGRAMMING FORM

ADDRESS	INSTRUCTION SYMBOL	CODE	WORKING STORAGE x	WORKING STORAGE y	WORKING STORAGE z	STORAGE REGISTERS
8	Data ↔ x	71				
1	3	23				aY_1
2	Data ↔ x	71			From thumbwheel #2	
3	7	27	866			
4	Data → xy	73				
5	4	24	200	866		
6	-	53	666			
7	GO SUB	13			Finish pumping on A	
8	2	22				
9	4	24				
9	1	21				
1	EXT	12			Turn off pump; release switch valve;	
2	9	31			release clamp (wait 1 sec)	
3	EXT	12			Seek position 3 (wait 1 sec)	
4	4	24				
5	GO SUB	13			Measure A	
6	8	30				
7	3	23				
8	1	21	N_{AM}			
9	Data → xy	73				
10	1	21	N_{AS}	N_{AM}		
1	GO SUB	13			Calculate Y_2	
2	9	31				
3	6	26				
4	1	21	Y_2			
5	7	27				
6	5	25			EPA constant "b" = 0.57	
7	EXP 1	21				
8	×15,-+	21				
9	×	57	bY_2			
11	Data ↔ x	71				
1	1	21				bY_2
2	-1	21	-1			
3	Data ↔ x	71				
4	5	25				-1
5	GO TO	17				
6	0	20				
7	2	22				
8	0	20				
9	y ↔ x	65	Y_1			

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5376A PROGRAMMING FORM

ADDRESS	INSTRUCTION SYMBOL	CODE	WORKING STORAGE x	WORKING STORAGE y	WORKING STORAGE z	STORAGE REGISTERS
12 0	Data $\overrightarrow{xy}$	73				
1	3	23	aY_1	Y_3		
2	+	52	aY_1+Y_3			
3	Data $\overrightarrow{xy}$	73				
4	1	21	bY_2	aY_1+Y_3		
5	+	52	$aY_1+bY_2+Y_3$			
6	Data $\overrightarrow{xy}$	73				
7	8	30	X/QM			
8	X	57	Y			
9	Data ↔ x	71			Print	Y
13 0	12	34				
1	y ↔ x	65	X/QM			
2	Data ↔ x	71				
3	12	34			Print	X/QM
4	GO TO	17			Go back to start	
5	2	22				
6	0	20				
7	0	20				
8	Clr $\overrightarrow{xyz}$	76			Start	of "count" subroutine
9	Int ↔ x	61				0
14 0	Data $\overrightarrow{xy}$	73				
1	4	24	200			
2	SQS ↔ x	60				
3	Mod A	42	p_i	n_i		
4	x ↔ y	65	n_i			
5	Int $\overrightarrow{xy}$	63	Σn_{i-1}	n_i		
6	+	52	Σn_i			
7	Int ↔ x	61				Σn_i
8	Data $\overrightarrow{xy}$	73				
9	7	27				
15 0	IFx<0	11				
1	GO TO	17				
2	4	24				
3	6	26				
4	1	21				
5	-1	21				
6	SQS $\overrightarrow{xy}$	62				
7	+	52				
8	IFx>0	10				
9	GO TO	17				

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HEWLETT hp PACKARD

5376A PROGRAMMING FORM

ADDRESS	INSTRUCTION SYMBOL	CODE	WORKING STORAGE x	WORKING STORAGE y	WORKING STORAGE z	STORAGE REGISTERS
16 0	2	22				
1	4	24				
2	1	21				
3	CONT	07				
4	Int $\overrightarrow{xy}$	63				
5	Data ↔ x	71			Print	Σn_i
6	12	34				
7	Int $\overrightarrow{xy}$	63				
8	Return	15				
9	:	56				
17 0	$\sqrt{x}$	45				
1	$\sqrt{x}$	45				
2	$\sqrt{x}$	45				
3	$\sqrt{x}$	45				
4	$\sqrt{x}$	45				
5	$\sqrt{x}$	45				
6	$\sqrt{x}$	45				
7	$\sqrt{x}$	45				
8	$\sqrt{x}$	45				
9	z ↔ x	75				
18 0	z → xy	77				
1	-1	21				
2	-	53				
3	z ↔ x	75				
4	CONT	07				
5	+	52				
6	z → xy	77				
7	:	56				
8	8	30				
9	4	20				
19 0	1	31				
1	EXP 7	26				
2	<15,+-	24		-1.48×10^{7}		
3	x	57	Y_i			
4	Int ↔ x	61				
5	Int ↔ xy	63				
6	Data ↔ x	71			Print	mass Y_i
7	12	34				
8	Int xy	63				
9	Return	15				

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HEWLETT hp PACKARD

Single Cycle

5376A PROGRAMMING FORM

ADDRESS	INSTRUCTION SYMBOL	CODE	WORKING STORAGE x	WORKING STORAGE y	WORKING STORAGE z	STORAGE REGISTERS
00	EXT	12			Stand-by.	Resets all solenoids.
01	(15)	37				TART CYCLE to continue)
02	Clr Data	16				
03	2	22				
04	EXP 2	22				
05	<15;++	25	200			
06	Data ↔ x	71				
07	(4)	24				200
08	EXT	12			Seek position 3 (wait 1 sec)	
09	(4)	24				
10	EXT	12			Seek position 2 (wait 1 sec)	
11	(2)	22				
12	GO SUB	13				
13	8	30				
14	3	23				
15	1	21	N_{BS}			
16	Data ↔ x	71				
17	(2)	22				N_{BS}
18	EXT	12			Seek position 1 and Hold (in MANUAL)	
19	(0)	20			(START PUMP to continue)	
20	EXT	12			Clamp solenoid; energize pump;	
21	(1)	21			energize switch valve.	
22	EXT	12			Switch flow counts to input of HP computer.	
23	(11)	33				
24	Clr xyz	76				
25	INT ↔ x	61				
26	Data ↔ x	71			From thumbwheel #1	
27	(6)	26			(COLLECTION TIME I)	
28	GO SUB	13				
29	2	22				
30	4	24				
31	1	21	N_{Flow}			
32	EXT	12			Release switch valve; release clamp;	
33	(9)	31			turn off pump (wait 1 sec).	
34	0	20				
35	0	20				
36	5	25			Flow constant "e" = 5×10^{-8}	
37	EXP 8	30				
38	<15,- +	21		N_{Flow}		
39	x	57	eN_{Flow}			

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HEWLETT hp PACKARD

Single Cycle

5376A PROGRAMMING FORM

ADDRESS	INSTRUCTION SYMBOL	CODE	WORKING STORAGE			STORAGE REGISTERS							
			x	y	z	INT	SQS	DATA 0	DATA 1	DATA 2	DATA 3	DATA 4	DATA 5
40	Data ↔ x	71											
1	3	23									(v)		
2	Data ↔ x	71									eN_{Flow}		
3	6	26											
4	SQS $\overrightarrow{xy}$	62											
5	-	53											
6	-1	21											
7	-	53	T_{pump}										
8	Data ↔ x	71											
9	5	25											T_{pump}
50	EXT	12											
1	2	22											
2	GO SUB	13											
3	8	30											
4	3	23											
5	1	21	N_{BM}										
6	Data $\overrightarrow{xy}$	73											
7	2	22	N_{BS}	N_{BM}									
8	GO SUB	13											
9	9	31											
60	6	26											
1	1	21	Y										
2	Data $\overrightarrow{xy}$	73											
3	3	23	V	$[m^3]$									
4	Data ↔ x	71			Print V								
5	12	34											
6	y ↔ x	65											
7	Data $\overrightarrow{xy}$	73											
8	3	23	V	Y									
9	:	56	C										
70	Data ↔ x	71											
1	12	34			Print C								
2	Data $\overrightarrow{xy}$	73											
3	5	25	T_{pump}										
4	Data ↔ x	71											
5	12	34			Print T_{pump}								
6	GO TO	17											
7	2	22			Go back to start								
8	0	20											
9	0	20											

5952-0654

HEWLETT hp PACKARD

5376A PROGRAMMING FORM

ADDRESS	INSTRUCTION SYMBOL	CODE	WORKING STORAGE x	WORKING STORAGE y	WORKING STORAGE z	STORAGE REGISTERS INT	SQS	DATA 0	DATA 1	DATA 2	DATA 3	DATA 4
8	Data ↔ x	71										
1	3	23										aY_1
2	Data ↔ x	71			From thumbwheel #2							
3	7	27	866									
4	Data $\overrightarrow{xy}$	73										
5	4	24	200	866								
6	-	53	666									
7	GO SUB	13			Finish pumping on A							
8	2	22										
9	4	24										
9	1	21										
1	EXT	12			Turn off pump; release switch valve;							
2	9	31			release clamp (wait 1 sec)							
	EXT	12			Seek position 3 (wait 1 sec)							
4	4	24										
5	GO SUB	13			Measure A							
6	8	30										
7	3	23										
8	1	21	N_{AM}									
	Data $\overrightarrow{xy}$	73										
10	1	21	N_{AS}	N_{AM}								
1	GO SUB	13			Calculate Y_2							
2	9	31										
3	6	26										
4	1	21	Y_2									
5	7	27		}								
6	5	25		}	EPA constant "b" = 0.57							
7	EXP 1	21		}								
8	<15,-+	21		}								
9	x	57	bY_2									
11	Data ↔ x	71										
	1	21							bY_2			
	-1	21	-1									
	Data ↔ x	71										
4	5	25										-1
	GO TO	17										
7	0	20										
8	2	22										
9	0	20										
0	y ↔ x	65	Y_3									

5952-0654

HEWLETT PACKARD

Single Cycle

5376A PROGRAMMING FORM

ADDRESS	INSTRUCTION SYMBOL	CODE	WORKING STORAGE x	WORKING STORAGE y	WORKING STORAGE z	STORAGE REGISTERS
12	Data $\overrightarrow{xy}$	73				
	3	23	aY_1	Y_3		
	+	52	aY_1+Y_3			
	Data $\overrightarrow{xy}$	73				
	1	21	bY_2	aY_1+Y_3		
	+	52	$aY_1+bY_2+Y_3$			
	Data $\overrightarrow{xy}$	73				
	8	30	X/QM			
	X	57	Y			
	Data ↔ x	71			Print Y	
13	12	34				
	y ↔ x	65	X/QM			
	Data ↔ x	71				
	12	34			Print X/QM	
	GO TO	17			Go back to start	
	2	22				
	0	20				
	0	20				
	Clr $\overrightarrow{xyz}$	76			Start of "count" subroutine	
	Int ↔ x	61				0
14	Data $\overrightarrow{xy}$	73				
	4	24	200			
	SQS ↔ x	60				
	Mod A	42	P_i	n_i		
	x ↔ y	65	n_i			
	Int $\overrightarrow{xy}$	63	Σn_{i-1}	n_i		
	+	52	Σn_i			
	Int ↔ x	61				Σn_i
	Data $\overrightarrow{xy}$	73				
	7	27				
15	IFx<0	11				
	GO TO	17				
	4	24				
	6	26				
	1	21				
	-1	21				
	SQS $\overrightarrow{xy}$	62				
	+	52				
	IFx>0	10				
	GO TO	17				

5952-0154

HEWLETT hp PACKARD

Single Cycle

5376A PROGRAMMING FORM

ADDRESS	INSTRUCTION SYMBOL	CODE	WORKING STORAGE x	WORKING STORAGE y	WORKING STORAGE z	STORAGE REGISTERS
16	2	22				
	4	24				
	1	21				
	CONT	07				
	Int $\overrightarrow{xy}$	63				
	Data ↔ x	71			Print	Σn_i
	12	34				
	Int $\overrightarrow{xy}$	63				
	Return	15				
	:	56				
17	$\sqrt{x}$	45				
	$\sqrt{x}$	45				
	$\sqrt{x}$	45				
	$\sqrt{x}$	45				
	$\sqrt{x}$	45				
	$\sqrt{x}$	45				
	$\sqrt{x}$	45				
	$\sqrt{x}$	45				
	$\sqrt{x}$	45				
	z ↔ x	75				
18	z → xy	77				
	-1	21				
	-	53				
	z ↔ x	75				
	CONT	07				
	+	52				
	z → xy	77				
	:	56				
	8	30				
	4	20				
19	1	31				
	EXP 7	26				
	×15,+-	24		-1.48×10^{7}		
	x	57	Y_i			
	Int ↔ x	61				
	Int ↔ xy	63				
	Data ↔ x	71			Print	mass Y_i
	12	34				
	Int xy	63				
	Return	15				

5952-1004

HEWLETT PACKARD

APPENDIX B

SCHEMATICS

REVISIONS				
LTR	ZONE	ECO AND DESCRIPTION	APPD	DATE

PREFIX	PART NUMBER	ITEM	QTY	NOMENCLATURE	B/M NO.

DIMENSIONS ARE IN INCHES AND INCLUDE PLATED FINISHES
FABRICATE PER PN 5701 9152-001
DO NOT SCALE DRAWING

TOLERANCES UNLESS OTHERWISE NOTED

XX	XXX	ANGLES	ALL MACH SURFACES
±	±	±	√

COMMERCIAL TOLERANCES ON STOCK SIZES
MACHINED DIAMETERS (DRC TO .005 T I R
MACHINED SURFACES TO BE MUTUALLY PERPENDICULAR OR PARALLEL WITHIN .003 IN INCH

NEXT ASSY | UNIT ASSY

PROPRIETARY DATA

This Drawing is for the use of Purchasers and users of AccuRay equipment and for use of vendors in the supply of parts, materials and services for such equipment. No disclosure reproduction or other use may be made except by written permission.

FINISH

DWN | CHKD | APPD

SPEC APPVL

PROD RELEASE

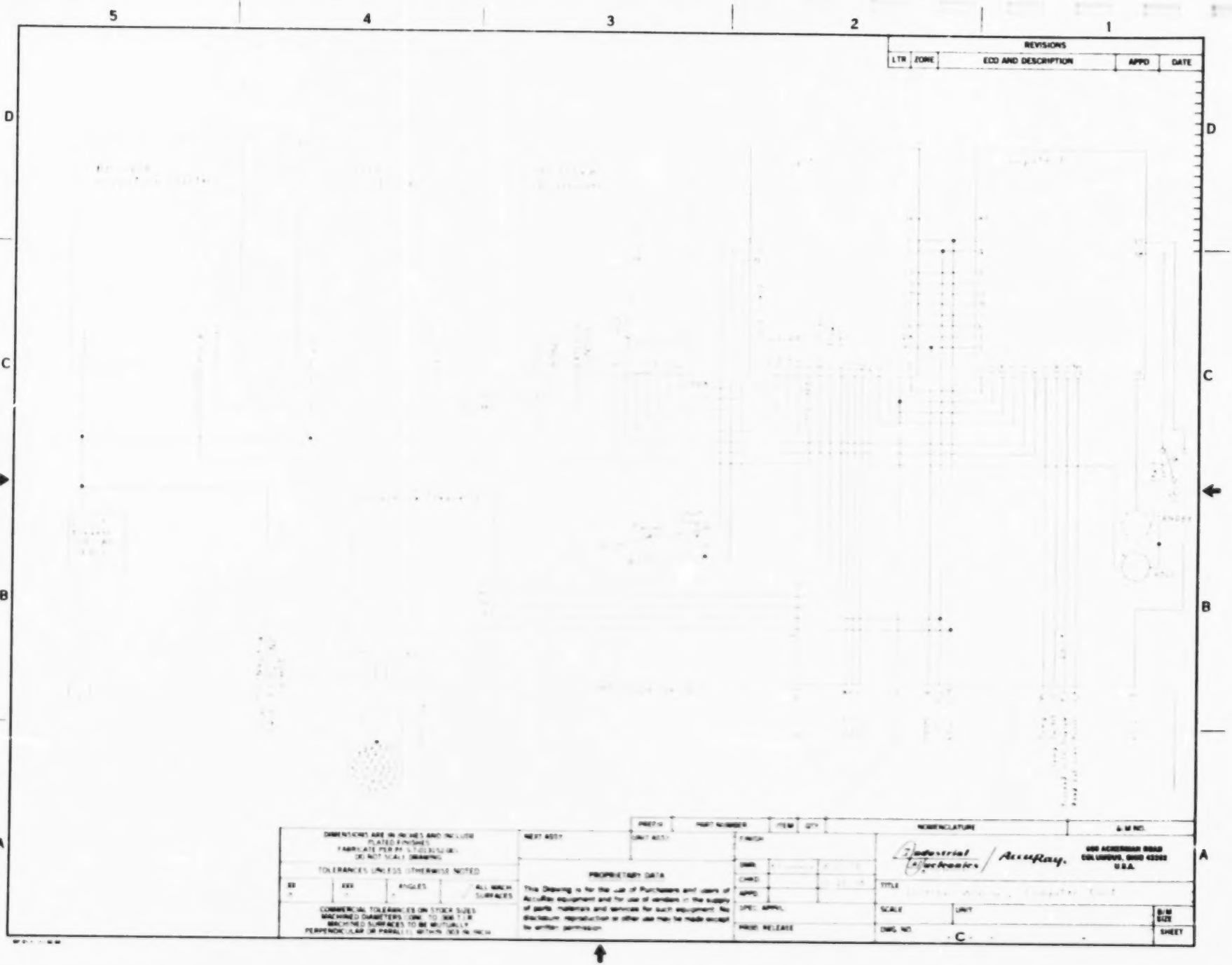
Industrial Electronics / AccuRay.

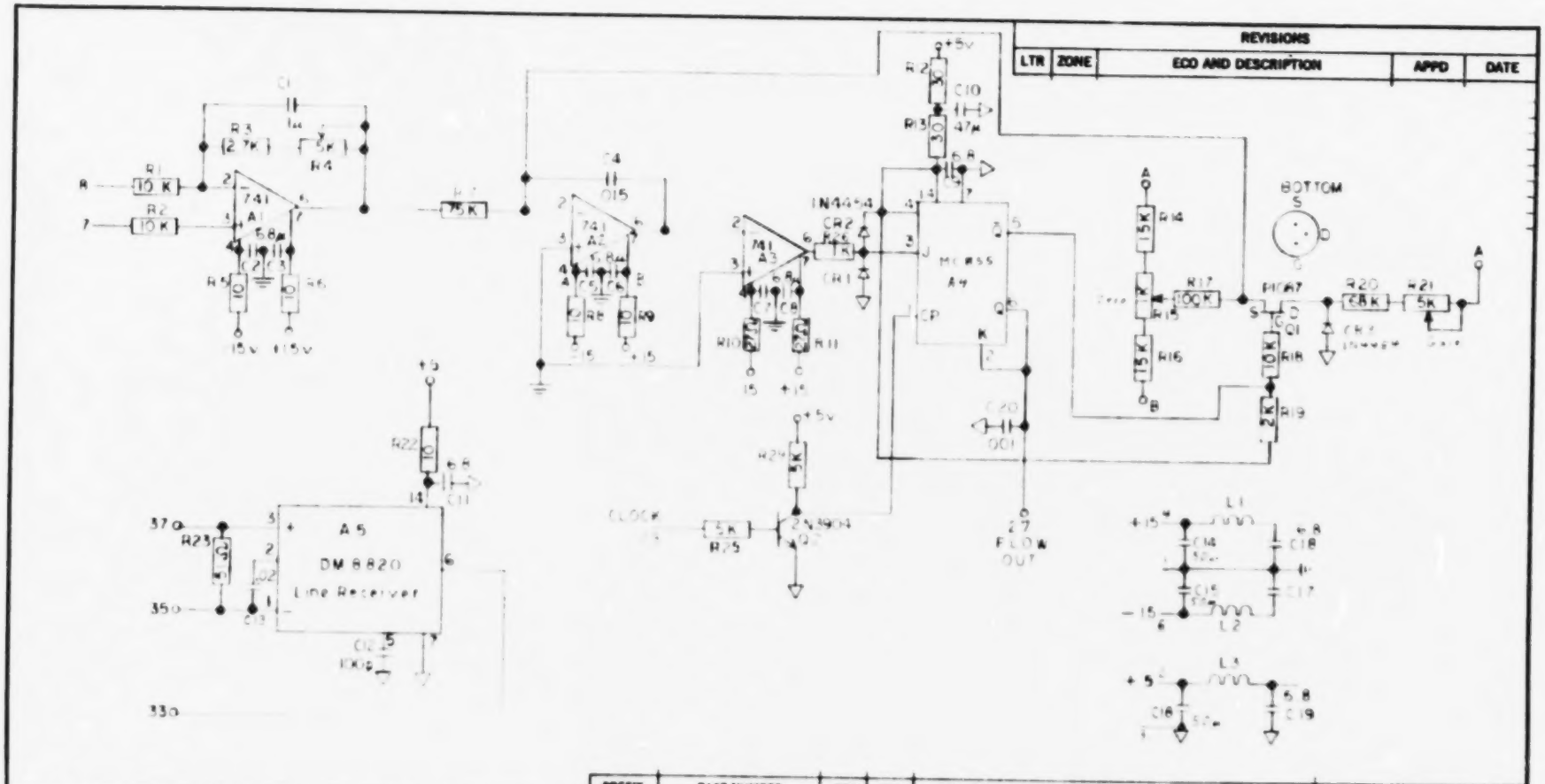
3590 ACKERMAN ROAD
COLUMBUS, OHIO 43228
U.S.A.

TITLE

SCALE | UNIT | B/M SIZE

DWG NO. C | SHEET


5
4
3
2
1
D
C
B
A
REVISIONS
LTR
ZONE
ECO AND DESCRIPTION
APPD
DATE
PROPRIETARY DATA
This Drawing is for the use of Purchasers and users of Accuray equipment and for use of vendors in the supply of parts, materials and services for such equipment. No disclosure, reproduction or other use may be made except by written permission.
Industrial Electronics / Accuray.
U.S.A.
TITLE
SCALE
UNIT
SHEET



PREFIX	PART NUMBER	ITEM	QTY	NOMENCLATURE	B/M NO.

DIMENSIONS ARE IN INCHES AND INCLUDE PLATED FINISHES
FABRICATE PER PF S-7-01315 2-001
DO NOT SCALE DRAWING

TOLERANCES UNLESS OTHERWISE NOTED

.XX ±	.XXX ±	ANGLES ±	✓ ALL MACH. SURFACES

COMMERCIAL TOLERANCES ON STOCK SIZES
MACHINED DIAMETERS CONC. TO .005 T.I.R.
MACHINED SURFACES TO BE MUTUALLY PERPENDICULAR OR PARALLEL WITHIN .003 IN/INCH

NEXT ASSY. | UNIT ASSY.

FINISH

DWN.
CHKD. 6-16-73
APPD.
SPEC. APPVL.
PROD. RELEASE

PROPRIETARY DATA

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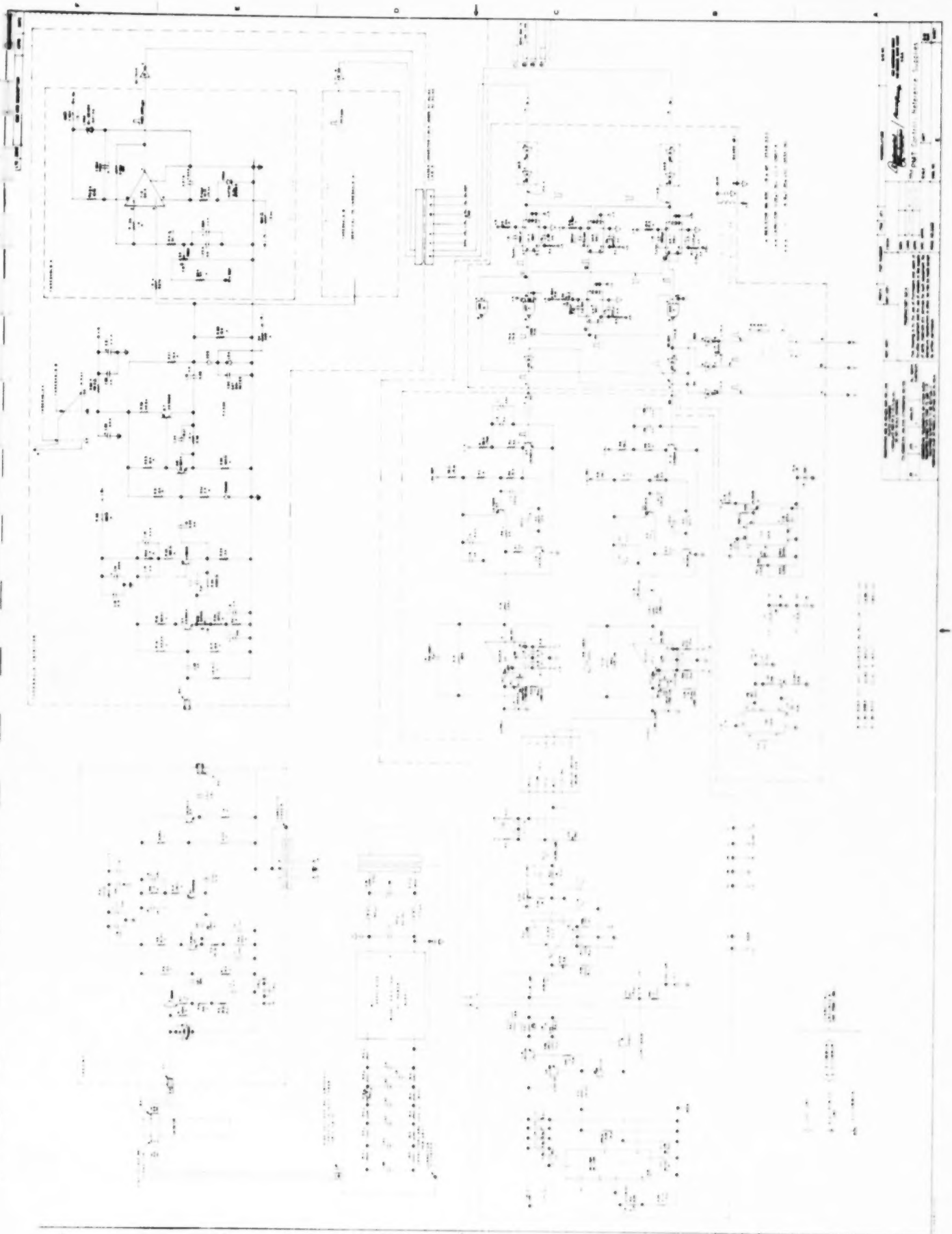
Industrial Electronics / AccuRay.

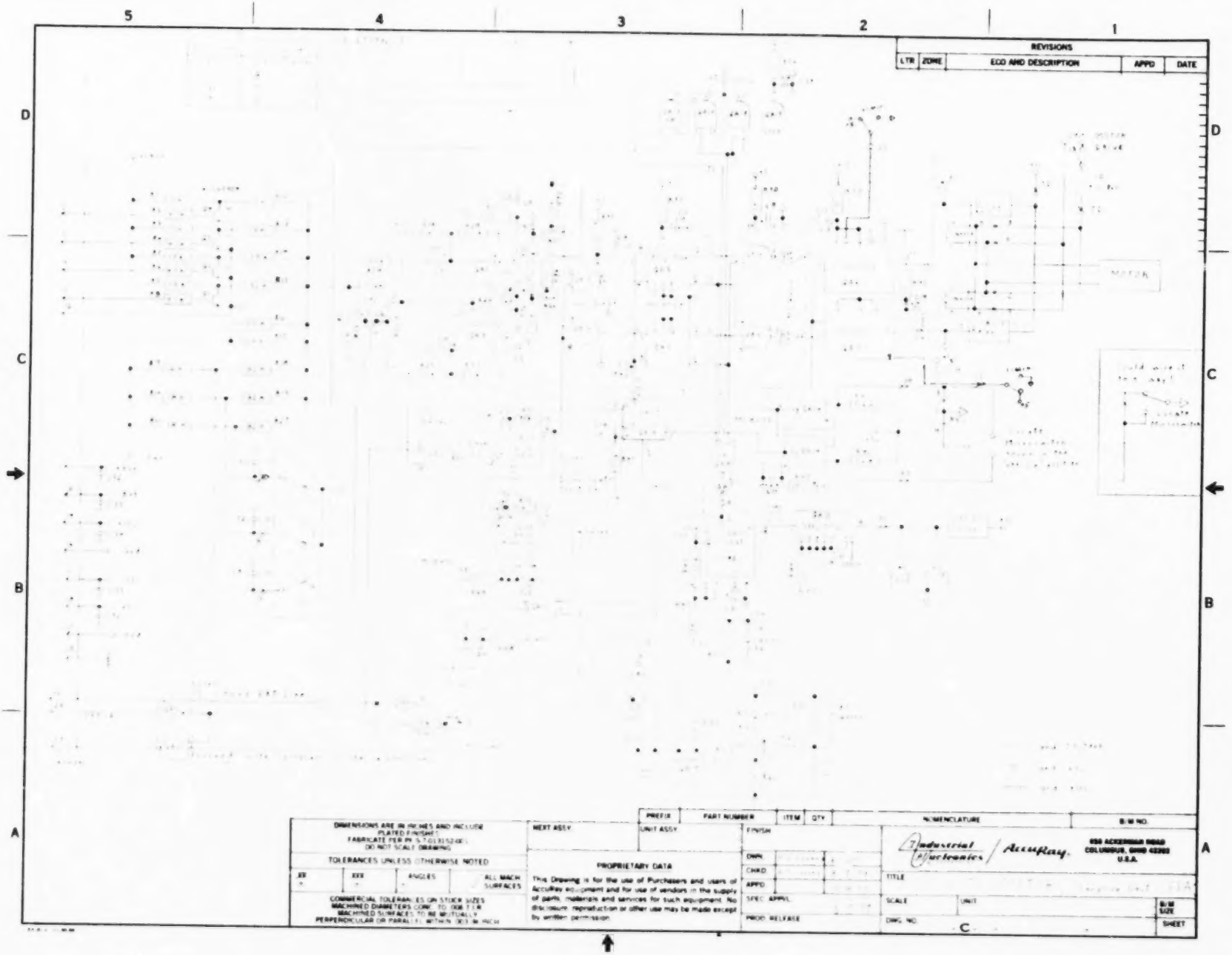
550 ACKERMAN ROAD
COLUMBUS, OHIO 43202
U.S.A.

TITLE FLOW SIGNAL

SCALE | UNIT | B/M SIZE

DWG. NO. - B - | SHEET




5
4
3
2
1
D
C
B
A
REVISIONS
LTR
ZONE
ECO AND DESCRIPTION
APPD
DATE
MOTOR
PREFIX
PART NUMBER
ITEM
QTY
NOMENCLATURE
B.M NO.
DIMENSIONS ARE IN INCHES AND INCLUDE PLATING IF INTENT
FABRICATE PER IPC-D-275
DO NOT SCALE DRAWING
TOLERANCES UNLESS OTHERWISE NOTED
XX
XXX
ANGLES
ALL MACH SURFACES
COMMERCIAL TOLERANCES ON STOCK SIZES
MACHINED DIAMETERS CONC TO .005 T.I.R.
MACHINED SURFACES TO BE MUTUALLY PERPENDICULAR OR PARALLEL WITHIN .001 IN INCH
NEXT ASSY
UNIT ASSY
PROPRIETARY DATA
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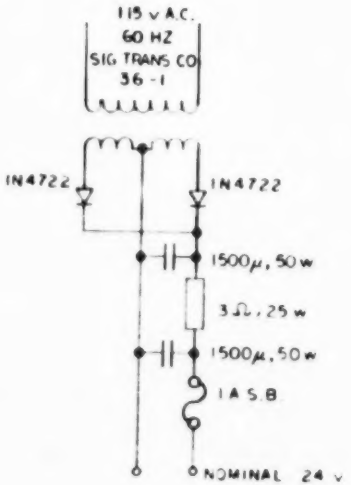
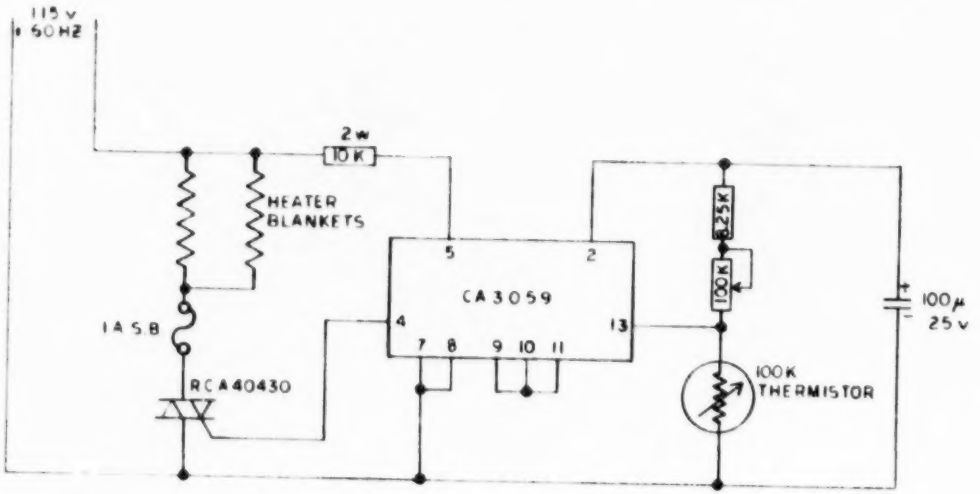
FINISH
DWN
CHKD
APPD
SPEC APPVL
PROD RELEASE
Industrial Electronics / Accuray
TITLE
SCALE
UNIT
B.M SIZE
DWG NO.
C
SHEET

C-23

REVISIONS				
LTR	ZONE	ECO AND DESCRIPTION	APPD	DATE



GEAR MOTOR SUPPLY



INLET PROBE HEATER CONTROL

PREFIX	PART NUMBER	ITEM	QTY.	NOMENCLATURE	B/M NO.

DIMENSIONS ARE IN INCHES AND INCLUDE PLATED FINISHES
FABRICATE PER PF S-7-013152-00
DO NOT SCALE DRAWING

TOLERANCES UNLESS OTHERWISE NOTED

.XX ±	.XXX ±	ANGLES ±	✓ ALL MACH. SURFACES

COMMERCIAL TOLERANCES ON STOCK SIZES
MACHINED DIAMETERS CONC. TO .005 T.I.R.
MACHINED SURFACES TO BE MUTUALLY PERPENDICULAR OR PARALLEL WITHIN .003 IN/INCH

NEXT ASSY.

UNIT ASSY.

FINISH

PROPRIETARY DATA

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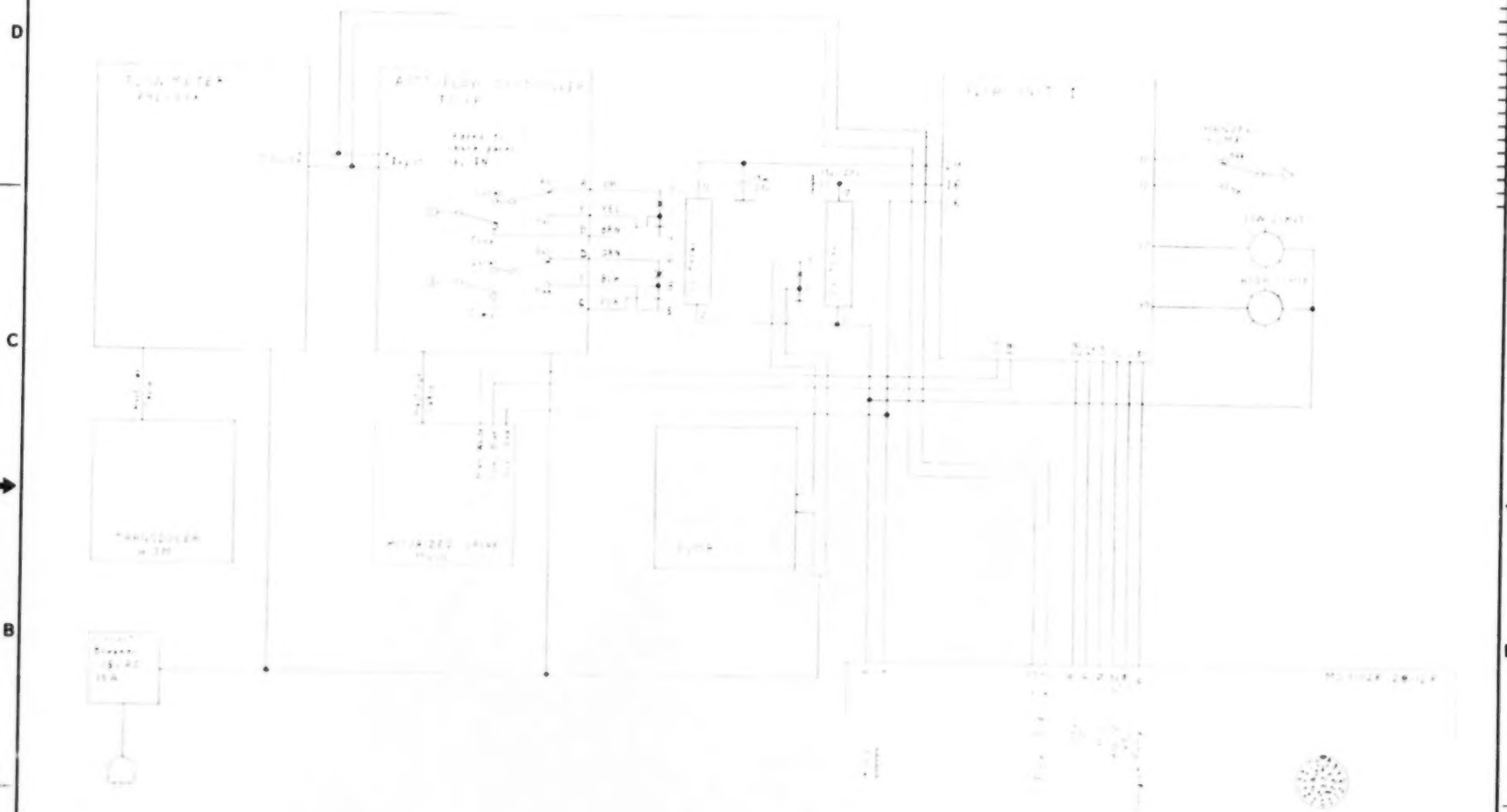
DWN.		
CHK'D.	[illegible]	6/22/73
APP'D.	[illegible]	6/25/73
SPEC. APPVL.		
PROD. RELEASE		

Industrial Electronics / AccuRay

880 ACKERMAN ROAD
COLUMBUS, OHIO 43202
U.S.A.

TITLE GEAR MOTOR & HEATER SUPPLIES

SCALE	UNIT	B/M SIZE
DWG. NO. - B -		SHEET



REVISIONS				
LTR	ZONE	ECO AND DESCRIPTION	APPD	DATE

PREFIX	PART NUMBER	ITEM	QTY	NOMENCLATURE	B/M NO.

DIMENSIONS ARE IN INCHES AND INCLUDE PLATED FINISHES
FABRICATE PER IPI S-7-013152-001
DO NOT SCALE DRAWING

TOLERANCES UNLESS OTHERWISE NOTED

XX	.XXX	ANGLES	ALL MACH. SURFACES
±	±	±	√

COMMERCIAL TOLERANCES ON STOCK SIZES
MACHINED DIAMETERS CONC. TO .006 T.I.R.
MACHINED SURFACES TO BE MUTUALLY PERPENDICULAR OR PARALLEL WITHIN .003 IN INCH

NEXT ASSY.

UNIT ASSY.

FINISH

PROPRIETARY DATA

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DWN.		
CHKD.		
APPD.		
SPEC. APPVL.		
PROD. RELEASE		

Industrial Electronics / AccuRay

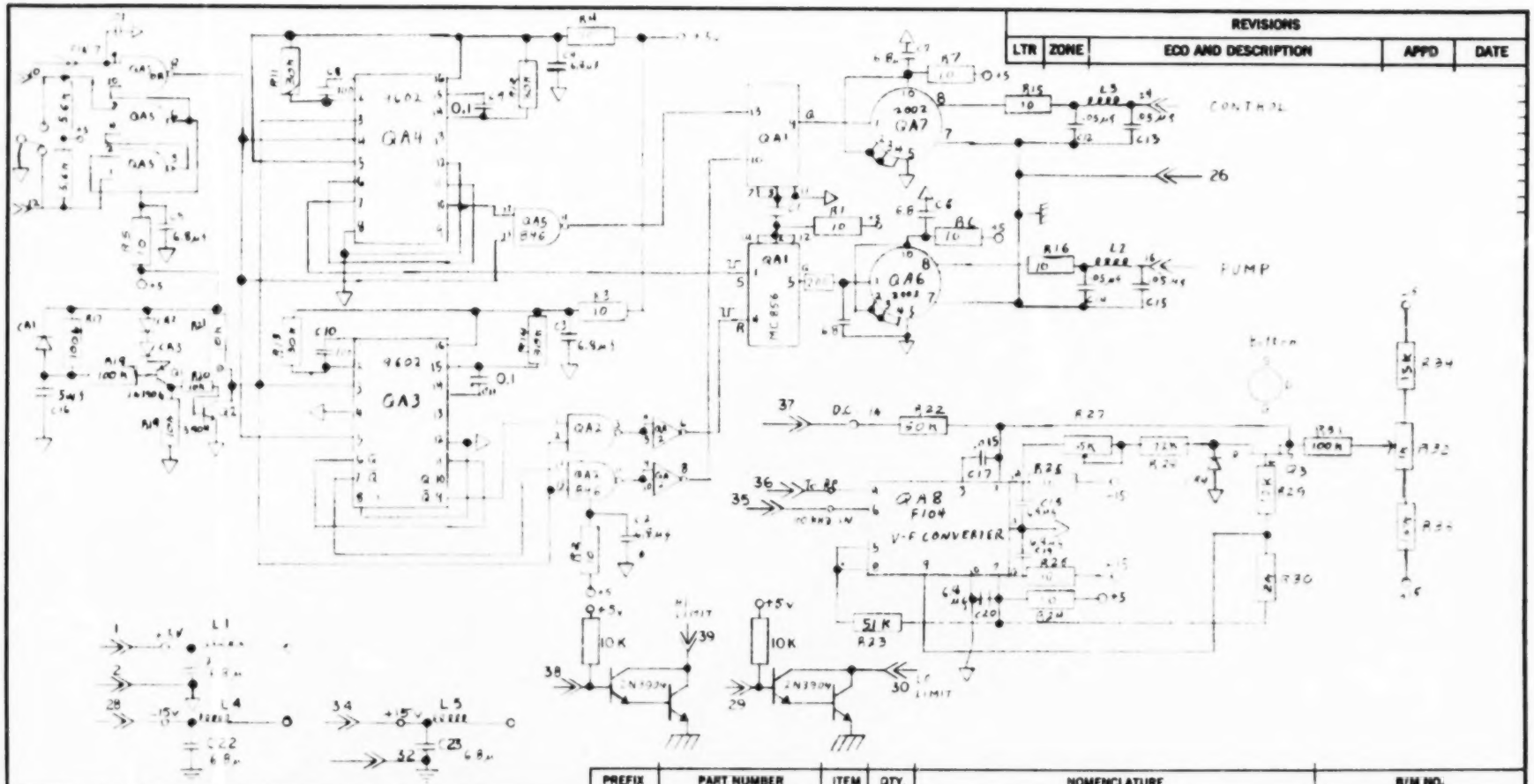
890 ACKERMAN ROAD
COLUMBUS, OHIO 43202
U.S.A.

TITLE

SCALE | UNIT | B/M SIZE

DWG. NO. - C -

SHEET


REVISIONS
LTR | ZONE | ECO AND DESCRIPTION | APPD | DATE
GA4
9602
GA3
GA5
GA1
GA2
GA7
GA6
MC856
CONTROL
PUMP
26
37
DL
36
35
GA8
F104
V-F CONVERTER
10K
2N3904
39
38
30
29
L1
L4
L5
28
34
32
DIMENSIONS ARE IN INCHES AND INCLUDE PLATED FINISHES
FABRICATE PER PF 5-7-013152-001
DO NOT SCALE DRAWING
TOLERANCES UNLESS OTHERWISE NOTED
XX ± | XXX ± | ANGLES ± | √ ALL MACH. SURFACES
COMMERCIAL TOLERANCES ON STOCK SIZES
MACHINED DIAMETERS CONC. TO .006 T.I.R.
MACHINED SURFACES TO BE MUTUALLY PERPENDICULAR OR PARALLEL WITHIN .003 IN/INCH
NEXT ASSY.
UNIT ASSY.
PROPRIETARY DATA
This Drawing is for the use of Purchasers and users of AccuRay equipment and for use of vendors in the supply of parts, materials and services for such equipment. No disclosure, reproduction or other use may be made except by written permission.
FINISH
DWN.
CHKD.
APPD.
SPEC. APPVL.
PROD. RELEASE
PREFIX | PART NUMBER | ITEM | QTY. | NOMENCLATURE | B/M NO.
Industrial Dynamics / AccuRay
888 ACKERMAN ROAD
COLUMBUS, OHIO 43202
U.S.A.
TITLE
PUMP & FLOW CONTROL
SCALE | UNIT | B/M SIZE
DWG. NO.
- B -
SHEET